SCIENCE READERS

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BY

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BOOK VII

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PREFACE

THIS book, like the others of the series, is intended to supplement the teacher's lessons, not to take their place; and if it is used in this way, with the help of the summaries, it cannot fail to drive home the experimental teaching.

It does not profess, as a text-book, to deal exhaustively with the subjects of which it treats. In each section a few simple lessons have been chosen with the object of leading up to a definite goal.

The clock, spectacles and other glasses, the mariner's compass, the lightning conductor, and so forth, are all of them common things, which must set an intelligent boy thinking; and the purpose of the lessons will be accomplished if they become an incentive to the pupil to follow up the study of these interesting subjects, whose threshold they have crossed in this simple way.

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BOOK VII

Lesson I

MATTER IN MOTION

DURING the course of these lessons we have been led, step by step, from a simple observation of the common things around us, to investigate some of the wonderful phenomena which are constantly going on before our eyes; and we have found that Nature works in her own appointed way, and by means of her own appointed agents, which we call the Natural Forces.

It will now be our province to enlarge the scope of those investigations, and to give a broader and deeper view of some of the wonderful workings of Nature.

You of course remember that we have one general name—matter—for every kind of substance or material thing which exists in, on, and around our world; and one of our earliest observations led us to discover that matter exists in three distinct states. We have solid matter, liquid matter, and gaseous matter.

You know, too, that this is no mere accident, but one of Nature's provisions. All matter is made up of molecules, and in a solid body these molecules are

held together by a mutually attractive force known as cohesion. But for this wonderful force everything around us, even our own bodies, would fall away in an impalpable dust—nothing would hold together.

This force of cohesion is not so strong in liquids as in solids; hence the molecules of a liquid have more freedom of movement, and the liquid is said to flow. There is no cohesion between the molecules of a gas. They mutually repel each other.

We become familiar with the various forms of matter through one or more of the five gateways of knowledge, or in other words through the five senses. Some things appeal to us through the sense of sight, some through the sense of touch, some through the sense of taste, some through the sense of smell, and some through the sense of hearing.

By means of these channels of observation we learn that all matter—solid, liquid, and gaseous—possesses certain properties. For example, all matter occupies space, has more or less weight, offers resistance, and transmits motion to other matter.

Let us for the present confine our attention to this last property, and it will perhaps help you to understand what that means, if we take a familiar illustration from the football field.

Picture the ball lying in the middle of the play at the commencement of the game. If it were not interfered with it would remain where it lies, for like all other dead helpless matter, it has no power of itself to move. It cannot move till some outside influence acts upon it.

It is the outside influence of the kick-off that sends it spinning towards the goal. It is the outside influ-

ence of the next kick, which changes the direction of its movement towards another part of the field. Here you see we have matter, in the form of the boy's foot, transmitting motion to the dead, helpless matter of the ball.

What do you say? "Why does the ball come to a standstill at last?"

Yes, that is a very thoughtful question, and I will answer it.

The ball is brought to a standstill by the roughness of the ground, which offers resistance to it, as it rolls along. This resistance, or friction as it is called, is another outside influence—another property of matter—but the effect of its action on the moving ball is to stop its movement, and bring it to a standstill.

The same ball, rolling over a smooth even surface of ice, would encounter less resistance—less friction—and hence would travel farther, but even that slight resistance would be sufficient to bring it to rest at last.

All outside influence, whatever it may be, which causes one body to move, and stops another already in motion, we shall henceforth call force. The particular force which sets the football in motion is the boy's bodily strength, and this is known as muscular force.

Savage people of all ages have known very little of any other force but their own bodily strength, and that of the animals they have been able to subdue. But there are many wonderful forces at work around us, and civilised man has learned, and is still learning how to adapt them to his service.

Just as the muscular force of the kick sets the ball in motion, or stops it when it is moving, so those other forces act upon all bodies—all matter—in nature, and produce similar results. Hence we speak of them as the Forces of Nature.

Let us take another illustration. You know that if you hold the ball out at arm's length and let go, it falls to the ground. But why does it fall? Ah! I see you remember. It falls because the earth itself possesses a wonderful attractive force called gravity. All matter, if unsupported, falls to the ground, because the earth's force of gravity attracts it.

You see from this that gravity and cohesion are both attractive forces; but the force of gravity produces motion, while the attractive force of cohesion prevents it.

Just one more thought now, before we leave this subject. Suppose I give you a heavy weight instead

of the ball to hold at arm's length. You could hold the ball for a considerable time, but as soon as you take the weight in your hand, you become conscious of a muscular strain.

The fact is the earth's force of gravity is attracting the object, but your own muscular force is trying to resist the downward pull which gravity is exerting. If the object is very heavy, the force of gravity will quickly overcome your muscular force, the struggle will soon be over, and the thing will fall to the ground.

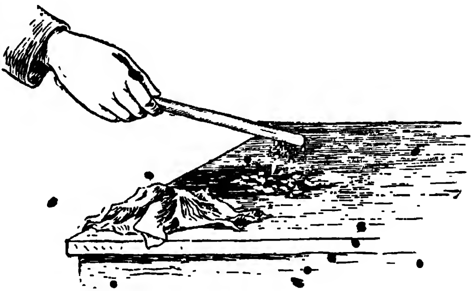
It is clear from this that gravity does not exert the same amount of force on all bodies. In other words we speak of the force with which gravity attracts a body as the weight of that body; and we say the body is light or heavy in proportion to the force with which gravity attracts it.

Let me lastly point out that the earth exerts the same attractive force, whether the object is placed on

not act upon all matter. We shall have more to say about this later on.

Let us take another simple experiment. I rub this glass rod with a piece of warmed silk, and then bring the rubbed end near some scraps of paper on the table. The little bits of paper instantly fly up towards the rod.

Here again we have a clear case of attraction. The rubbed glass attracts, or draws to itself, those light substances, by means of a wonderful force which it possesses.



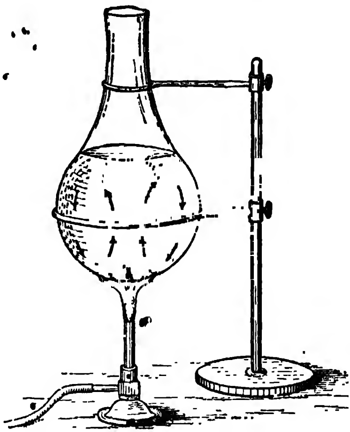
Let us try it again with the other end of the rod, which has not been rubbed. There is no movement among the scraps of paper now, you see. Hence it is clear that the attractive force, which first caused the movement, was not originally in the glass—it must have been produced by rubbing the rod with silk.

This wonderful force — another of the Natural Forces—is known as electricity. It is closely allied to the other force—magnetism. We shall deal with both of them more fully by and by.

I think I have now made it clear to you that

cohesion, gravity, magnetism, and electricity are all of them attractive forces.

Suppose we pass on from this to consider some of Nature's other forces. I stand a flask of water over the Bunsen burner, and watch it till it boils. What do I see? Particles of water move upwards in a constant stream to the surface under the influence of the heat.



Yes, I am sure you are all ready to explain the meaning of this. The effect of heat is to overcome the force of cohesion. The molecules of a body are driven apart under the influence of heat, so that they occupy more space.

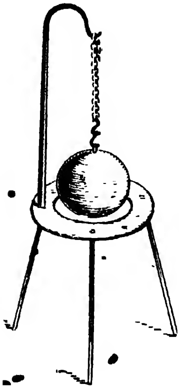
As the heated molecules occupy more space than the rest, they are relatively lighter, and are forced upwards by the buoyancy of the liquid.

Heat is another of the Natural Forces, but unlike those we have already considered, it exerts a repulsive, not an attractive influence.

We can see for ourselves this repulsive influence, as the water in the flask receives the heat from the burner. We can see the result of it too, if we hold a bladder, partly filled with air, in front of the fire; for as the air inside becomes expanded with the heat, it spreads out and fills the bladder.

You no doubt remember our experiment with the

brass ball and the ring. We could not, it is true, actually see the molecules of the brass ball move, but we know they must have moved, because the ball, after it was heated, was too big to pass through the ring. Its molecules had been driven apart by the repulsive force of heat.



Heat, you remember, travels from one body to another in straight lines. These lines of heat we call rays, and we say that heat travels by radiation.

The sun, the source of all our heat, warms the earth by radiation; but we must also remember that the solar rays give light as well as heat, and this will naturally lead us to make some inquiry as to the nature of the solar rays themselves.

It is generally believed that the fiery orb of the sun is in a constant state of rapid vibration among its particles; and that the vast space between the sun and the earth is pervaded by an extremely thin, impalpable fluid, which, for want of a better name, has been called ether.

The phenomenon of light is then accounted for in this way.

"The vibration in the substance of the sun itself sets up a series of waves in the surrounding medium—this all-pervading ether; and the ether-waves travel with a motion similar to that which would be produced, if one end of a long cord were tied to a post, and the other end were shaken or jerked up and down.

"The ether-waves produced in this way travel with

immense velocity, and when at last they strike on the retina of the eye, they give rise to the sensation of light.

"The immense velocity of these ether-waves is shown by the fact that some of them make no less than 727 million millions of vibrations every second.

"Light therefore, as an influence capable of producing motion, is rightly regarded as another of the Forces of Nature."

But let us continue our investigations. I strike this tuning fork on the table, and while it is sounding, I will bring it lightly in contact with this sheet of paper.

The fork is in a state of vibration; little taps can be distinctly heard as it vibrates against the paper. But if I press the paper against the fork, the quivering ceases, and so does the sound.

If you strike the fork again, and while it is sounding bring it into contact with your teeth, the vibrations can be distinctly felt; but as soon as the vibrations cease, the sound ceases too.

This simple experiment will be quite sufficient to prove that sound is the result of vibration, and that without vibration there can be no sound.

You all know the effect of throwing a stone into a pond of water. That will help you to form a good idea of the manner in which these sound vibrations are communicated.

The vibrations set up in the sounding body are communicated to the air around by a series of waves, which spread out in widening circles, in some such way as the circles spread in the water.

When these air-waves reach the ear, and strike on the nerve of hearing, they give rise to the sensation of sound.

Sound therefore is an influence which produces motion. It is another of the Forces of Nature.

Summary of the Lesson

1. Cohesion, gravity, magnetism and electricity are attractive forces.
2. Heat expands bodies by driving its molecules farther apart.
3. Heat is a cause of motion; it is, therefore, one of Nature's forces.
4. Light is conveyed through space by the rapid vibration of the ether-waves.
5. It is a cause of motion; and is therefore another of Nature's forces.
6. Sound is the result of vibration.
7. It is conveyed by a series of waves, which spread out in circles through the air.

Lesson III

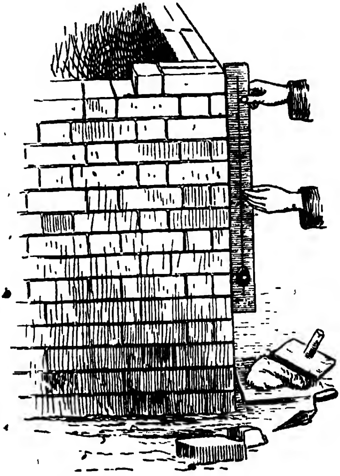
The Builder's Plummet

We know that matter of all kinds possesses weight, although some bodies have more weight than others; and we have found that this property of weight is due to the force of gravity, which attracts all matter towards the earth.

The weight of a body causes a downward pressure, which is in proportion to the force with which gravity attracts it, and if we represent the direction of this downward pressure by a line, we say that the line is vertical or upright.

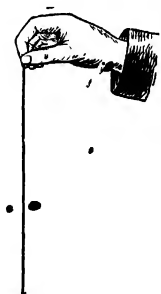
No doubt you have all seen a plumb-line or plummet, and you know that the builder uses the instrument to test the uprightness of his work.

He can see at a glance whether the wall he is building is upright or not, because the cord of the plummet always hangs in a vertical or upright line.



And yet it is a very simple contrivance, for it consists merely of a cord with a weight attached to one end, and every similarly-weighted cord hangs in the same direction.

Tie a stone to the end of a string, and set it swinging from side to side. Then if you let it come to rest, you will find that it always returns to the same position, with the string hanging in a vertical line.



Now hold the cord so as to allow the stone to dip into the water in this bowl, and you see at once that the surface of the water is at right angles to the vertical line of the hanging cord.

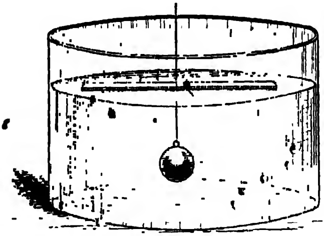
It would be exactly the same if we allowed the stone to dip down into a pond, a lake, or any other great body of water on any part of the earth's surface. The downward pressure of the stone, owing to the attractive force of gravity, would cause the cord to hang

in a vertical line, and at right angles to the surface of the water.

We say that the surface of the water forms a horizontal plane, and this is always at right angles to the vertical cord.

We often use these two terms—horizontal and vertical. Let us see what they really mean.

With the help of the chalk, and a piece of string to act as a radius, draw on the blackboard or on a



wall a very large circle. Then fix upon some point outside the circle, and from it rule a straight line to the centre. Then from the spot where the line cuts the circle measure off a small piece of the circumference, say half an inch on either side.

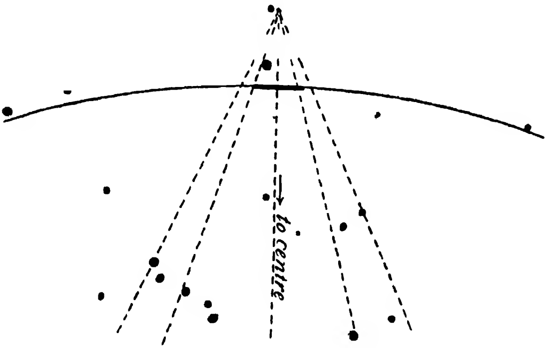
That done you will no doubt be very much surprised, if you place the edge of a straight ruler close up against this small section of the circle, for you will find that this little piece of the circle is as straight as the ruler itself.

Strange as it may seem, it is still perfectly true

that any small piece of the line, in any part of the circumference, appears to be quite straight.

The fact is, the piece is so small compared with the size of the circle itself that we do not notice any roundness or curve in it.

Picture to yourselves, as a further illustration, a great ball, say a yard across, and suppose we could cut away a piece of its surface about the size of a sixpence, just as we remove a piece of the shell from an egg.



That little piece of the round ball would lie flat on the table, for it would itself be quite flat.

Now let us apply this to the great ball on which we live. Our earth is 25,000 miles round, and at the best we can see only a very small part of its surface at one time. The part of it which we see is like the little piece of the ball. It appears quite flat, and this is particularly noticeable out on the open sea, where there is nothing to obstruct the view, for there, on every side, stretches the same level, horizontal surface of water.

It is this apparent flatness of the earth's surface, which makes it so difficult for young people to believe that they live on an immense ball.

Let us turn once more to our drawing on the board. That little section of the circle, which lies straight and even with the ruler, represents the level or horizontal surface of the earth or water at any particular spot, and you know that the vertical line at right angles to it passes through the centre of the circle.

Now imagine yourself anywhere you please on the earth's surface with the plummet in your hand. The plumb-line, of course, would hang downwards, and in a vertical direction, and it is perfectly clear that, if the line of that direction were continued, it must pass through the centre of the earth.

I think you will now clearly understand that every vertical line at every spot on the earth's surface must, if produced, pass through its centre; and that bodies hang and fall in a vertical line, because the force of gravity attracts them to the earth's centre.

This makes it quite clear that the centre of the earth is the centre of the earth's force of gravity.

Summary of the Lesson

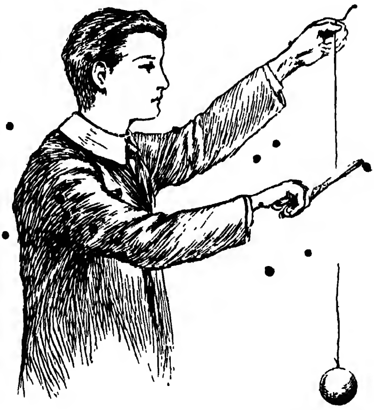
1. Suspended bodies hang in a vertical line.
2. A horizontal plane is at right angles to the vertical line of a plummet.
3. The vertical line of the plummet, if produced, would pass through the centre of the earth.
4. The centre of the earth is the centre of its force of gravity.

Lesson IV

Gravitation

In our last lesson the builder's plummet made it clear that the centre of the earth is the centre of the earth's force of gravity.

We are now in a position to carry our investigations a step farther, and with that aim in view let us refer once more to the ball or stone suspended at the end of the string.



When you hold the cord in your hand with the ball at the opposite end, it hangs in a vertical line; and you observe that if I cut the cord through with the scissors, the ball falls to the floor in the same vertical line.

It falls in that direction because it is attracted by the force of gravity which acts from the centre of the

earth. You have already seen that every vertical line, at every spot on the earth's surface must, if produced, proceed direct to its centre.

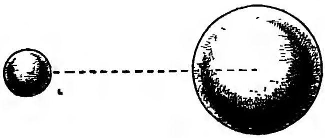
Of course you have heard the story of Sir Isaac Newton and the falling apple. He had, no doubt, seen many an apple fall from trees before, but on that occasion it set him thinking.

He began by asking himself the question, "Why did the apple fall *to* the ground, and not *away from* it?"

This question, simple as it seems, led him on not only to investigate the earth's force of gravity, but to

discover, step by step, the mutual relation which exists between the earth, the sun, the moon, and the other heavenly bodies.

After many years of patient experiment and research, he came to the conclusion that there is a universal force in Nature, by virtue of which every



material body attracts every other material body, and this universal force he called gravitation.

He further discovered that the attraction between any two bodies acts in a line joining their centres, and that the attraction exerted by each body is directly

proportioned to its mass, or in other words the greater the mass of matter, the greater the attractive force which it possesses.

Now let us apply this to the suspended ball. You already know that the earth attracts the ball; but it is equally important to remember that the ball in its turn attracts the earth, their mutually attractive forces acting in a line joining their centres.

The tendency of this mutual attraction is to cause the ball and the earth to move towards each other along this line.

But the mass of matter in the earth is immeasurably greater than the mass of matter in the ball, and therefore the force with which the earth attracts the ball is immeasurably greater than that, with which the ball attracts the earth.

Hence, if we say that the ball moves as much farther than the earth, as the earth's mass is greater than the mass of the ball, we practically mean that the earth remains stationary, and only the ball moves when the cord is cut.

Sir Isaac Newton, as I have already observed, did not stop here. He discovered that this force of gravitation affects every material body throughout the universe; and we are thus enabled to account for the movements of the earth and the other planets in their orbits round the sun.

The sun attracts the earth, and the earth in its turn attracts the sun, their mutually attractive forces acting in the line which joins their centres.

But the mass of matter in the sun is vastly greater than the mass of matter in the earth. Hence the attraction which the sun exerts on the earth is vastly

greater than that which the earth exerts on the sun.

For practical purposes, therefore, we may regard the sun as a stationary body, with the earth and the planets moving round it, and the mutual attraction of gravitation between it and them keeps them in their regular paths or orbits.

Newton was able at last to embody the results of his investigations in three statements, and these he called the Laws of Gravitation.

They are :—

1. Every material body in Nature attracts every other material body at all distances.

2. For the same distance the attractions between bodies are directly proportioned to their masses.

3. The intensity of this attraction varies inversely with the square of the distance.

The first and second of these laws have already been dealt with. Let us see what we can make of the third.

Of course you know that the square of any number is the product obtained by multiplying that number by itself. Thus $4 = 2 \times 2$; $9 = 3 \times 3$; $100 = 10 \times 10$, and therefore 4, 9, and 100 are respectively the squares of 2, 3, and 10.

You know, too, that when we turn a thing upside down, we are said to invert it, as you do in Arithmetic when you invert a fraction. Thus $\frac{5}{6}$, when it is inverted, becomes $\frac{6}{5}$, and we say $\frac{6}{5}$ is the inverse of $\frac{5}{6}$.

Similarly 4, *i.e.* $\frac{4}{1}$ becomes $\frac{1}{4}$: 9, or $\frac{9}{1}$ becomes $\frac{1}{9}$; and 100, or $\frac{100}{1}$ becomes $\frac{1}{100}$, when inverted. So that $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{100}$ are respectively the inverse of the squares of 2, 3, and 10.

Now let us see what Newton's third law really means.

It means that if the distance between two bodies is doubled, the attraction of gravitation between them is only $\frac{1}{4}$ of what it was; if the distance is trebled, the attractive force is diminished to $\frac{1}{9}$ of its original intensity; and if it is increased 10 times, the attraction is only $\frac{1}{100}$ of the original.

Summary of the Lesson

1. Gravitation is the general name for the force by which every material body in the universe attracts every other material body.

The laws of gravitation are:

(*a*) Every material body attracts every other material body at all distances.

(*b*) For the same distance the attractions between bodies are directly proportioned to their masses.

(*c*) The intensity of this attraction varies inversely with the square of the distance.

Lesson V

The Centre of Gravity

That ball suspended at the end of the cord has helped us to form a clear conception of gravity and gravitation; let us now see what further use we can make of it.

Take one end of the cord in your hand as before, and you know that the ball at the opposite end hangs in one constant position, because it is under the influence of gravity, which acts in a vertical line from the centre of the earth to the centre of the ball.

It is clear, then, that this vertical force of gravity

acts in a direct line with the cord which supports the ball, for the cord is vertical too.

The fact is, this force of gravity, which tends to draw the ball downwards to the earth, is neutralised by the opposing upward pull or tension of the cord. In other words, the two opposing forces hold each other in check, and the ball is said to be in equilibrium.

If I cut the cord I upset the equilibrium, and the force of gravity, being no longer held in check, has it all its own way, and the ball falls.

Let us take another illustration of this. I balance a ball on one end of a stick, and you know that the force of gravity acts upon it there as well as in any other position. What prevents it from falling to the earth?

The downward pull of gravity, acting through its centre, is neutralised in this case by my muscular force, which offers an upward resistance at the top of the stick. Those two opposing forces hold each other in check, and hence the ball in this position is said to be in equilibrium.

I need scarcely remind you that every individual particle of matter in the ball has weight. In other words, every individual particle is pulled downwards by the force of gravity.

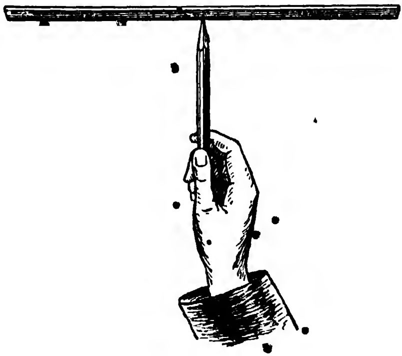
The single force which acts through the centre of the ball is simply the sum of all those individual attractions due to gravity. Hence the centre of the ball is said to be its centre of gravity, or that point through which the sum of all those individual attractions must pass.

Imagine the ball cut through its centre so as to make two hemispheres. Then, of course, exactly half

the matter of the ball would be on one side of the division, and half on the other side, and the attractions due to gravity on the opposite sides of the ball must be equal.

Hence the ball itself rests in equilibrium, because these individual attractions balance each other on its centre—that is, on its centre of gravity.

You will perhaps understand this better if you place one of your flat rulers on the point of an upright pencil, exactly six inches from either end.



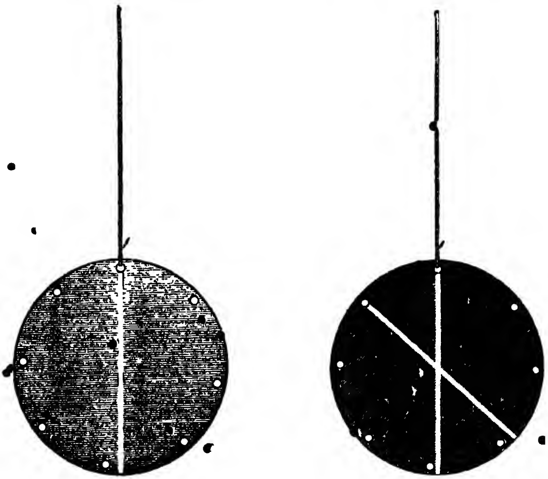
The ruler remains at rest in the horizontal position, without any tendency for either end to move, and we say it balances itself.

That spot which rests on the tip of the pencil is its centre of gravity; and all the individual attractions, which gravity is exerting upon every particle of matter in the ruler, balance on this one spot.

If you try to balance a rough irregularly-shaped stone on the stick, you find it is not so easily done. But the stone, as well as the ball and every other material body, has its centre of gravity—that is, a

point through which the sum of all the individual attractions due to gravity must pass, and on which they all balance themselves.

This point is not so easily found in the rough stone, for it is not in the actual centre of all bodies, as it is in the ball; but a little patience will find it, and a body always balances itself on its centre of gravity.



Let us now proceed to find the centre of gravity of a few variously-shaped objects.

Suppose we commence with this circular wooden disc, which I will suspend by a cord from some point near the circumference, either by means of a clip, or a hole drilled through it.

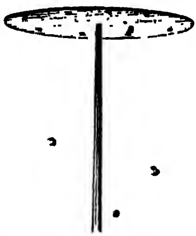
As it hangs, the attraction of gravity will, of course, keep the supporting cord vertical, and if I rule a chalk line across the disc in the direction of the cord itself, you know, from what we have already seen, that the

centre of gravity of the disc must be somewhere in that vertical line.

We will now suspend the disc from some other point, and in that position repeat the operation of drawing a vertical line across it with the white chalk as before. That done, it is clear that the centre of gravity of the disc must be somewhere in this line, and hence as it is somewhere in both these lines, it can only be at the point where they cross each other.

This point, if tested by actual measurement from the circumference, is found to be the true centre of the plate.

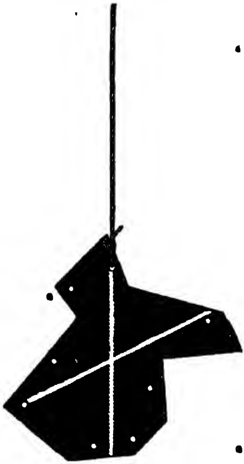
The disc will readily balance on a pencil at this point, and if it is suspended by a cord from the same point, it will remain at rest in the horizontal position. Hence we know that the centre of gravity of a circular plate of any kind is at its actual centre.



If we pass on from this to deal in a similar way with other regular figures, such as squares, oblongs, and triangular plates, we find that the point where the chalk lines cross is in every case coincident with the actual centre of the plate.

We can balance each one on its centre, and it will remain at rest or equilibrium in the horizontal position, because the centre of gravity in all circular, square, oblong, or triangular plates is at their actual centres.

By suspending any irregularly-shaped plate of metal, slate, wood, or cardboard from different points in the same way, we can always find its centre of gravity, which will be where the vertical lines cross; but that point when found will not be the actual centre, for such a figure has no proper geometrical centre.



Now lastly, suppose we had a number of these plates, of the same shape and size, piled one upon another. The pile of square plates would make a solid cube, or a square prism. The circular plates would make a solid cylinder. The oblong plates would make a rectangular prism, and the triangular ones a triangular prism.

It is clear that, as the centre of gravity is in exactly the same spot in each plate, those spots will lie one above another in the pile or column. That is to say, they will form a straight line from bottom to top.

The central point of this line must be the middle plate of the pile, and that point, of course, is the centre of gravity of the whole solid mass.

Summary of the Lesson

1. When two or more forces, acting on a body balance each other, the body is said to be in equilibrium.
2. The centre of gravity of a body is that point, through which the sum of all the attractions due to gravity must pass.
3. A body will always balance itself on its centre of gravity.

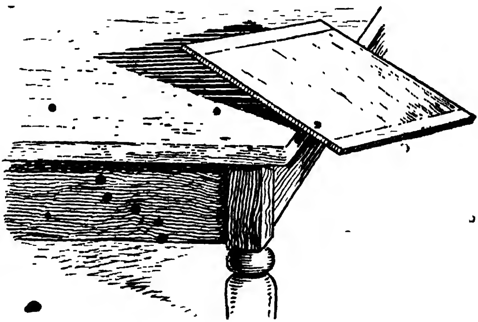
4. The centre of gravity of a circular, square, oblong, or triangular plate is at the geometrical centre in each case.

5. To find the centre of gravity of a solid block, imagine the block to consist of separate slices piled one on the other.

Lesson VI

EQUILIBRIUM AND THE CENTRE OF GRAVITY

In our last lesson we had a few experiments in balancing certain objects, and we learned that a body always balances itself on its centre of gravity.



Let us continue our investigations, by endeavouring, in the same practical way, to find the centre of gravity of this drawing-board.

In the first place, you remember that to find the actual centre of the board we have only to draw the two diagonals, and the point where they cross is the centre.

Now I will lay the board flat on the table, with those diagonals marked in coloured chalk on the

under side, and gradually move it towards the edge till it overlaps and begins to sway. Then, while it balances in this position, I will run a chalk line along the under side, to mark where it rests on the edge of the table.

That done, we will place it in another position and repeat the operation by balancing it once more on the edge, marking, as before, the line on which it balances.

If after this we turn the board over for inspection, we find that these newly-drawn lines cross each other at the intersection of the diagonals. The board balances on this point, which is therefore its centre of gravity; and we can find the centre of gravity of any flat plate in the same way, by balancing it in different positions on the edge of a table.

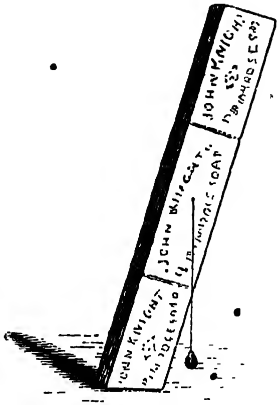
Now push the board slowly forward, and you will observe that it will remain at rest, as long as its centre of gravity is within the edge of the table, but immediately the centre of gravity is beyond the edge it will fall over.

Let us imagine a number of these boards placed one on the other to form a solid block. The centre of gravity of the pile thus formed, you remember, is in the centre of the middle board.

It is clear that if a vertical line from this centre of gravity falls upon the table, as the base of support, the pile will remain in equilibrium. But if the vertical line falls outside the edge of the table, the whole mass will topple over.

Let us go a step farther. I will stand this bar of soap on its end in the middle of the table. You will easily understand that its centre of gravity is at the central point of the bar, and a vertical line from that

point to the base of support. That explains why the bar in its present position stands erect—it is in equilibrium.



Now observe what happens if I cut off a thin wedge-like slice from the lower end of the bar, and try to stand it on its new base.

It cannot be made to stand; even when we support it, the column leans over in a slanting position, and if it is left to itself it falls over at once.

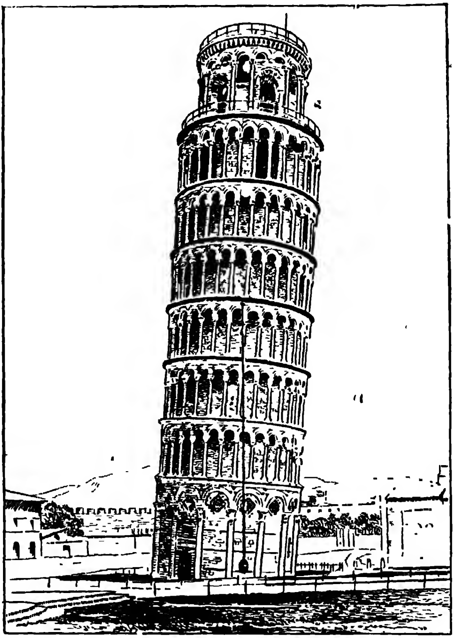
You will see the reason for this at a glance, if I hold a short weighted cord (a sort of plummet) from the centre of gravity of the bar; for the vertical line, as shown by this cord, falls outside the base of support, and under these conditions there can be no equilibrium—the body, whatever it is, must fall.

No doubt you have read of the famous Leaning Tower of Pisa in Italy. This tower, which is 179 feet high, leans 13 feet out of the perpendicular; but the vertical line from its centre of gravity, as tested by the plummet, falls within its base of support, not outside it. Hence the tower has stood firm for centuries, and is likely to stand for centuries to come.

Now if I place one end of the drawing-board on some books, I make an inclined plane, and I want you to observe for yourselves what happens, when I stand

the square end of the bar of soap on this slanting surface.

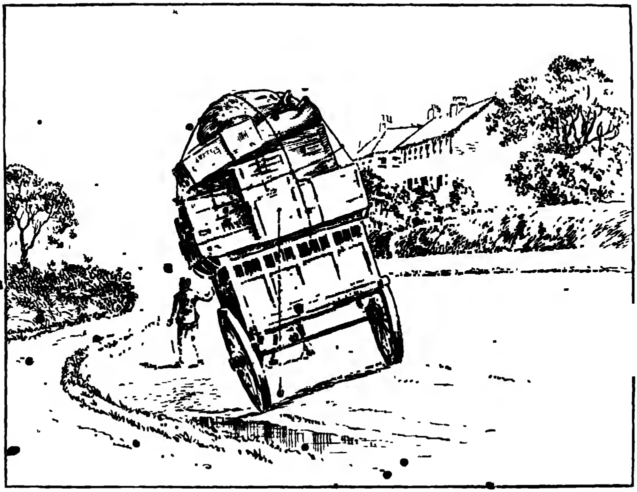
The bar, you see, leans in a slanting position, and will not stand of itself. The reason will at once be clear, if you test, as before, with the plummet, for you will see that the vertical line from the centre of gravity



falls outside the base of support, and in such a case there can be no equilibrium—the body must fall.

Let us take as an illustration of this, a heavily-loaded cart on a hillside. Of course the base of support in this case is the ground between the two wheels.

The cart will travel safely, if the vertical line from the centre of gravity falls between the wheels. But if



the vertical line falls beyond the lower wheel, the cart will be overturned.

Summary of the Lesson

1. If the vertical line from the centre of gravity falls within the base of support, the body will remain in equilibrium.

2 A loaded cart will travel safely over an uneven, hilly road so long as the vertical line from the centre of gravity falls between the wheels.

Lesson VII

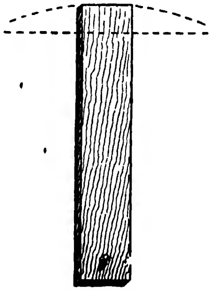
Stable and Unstable Equilibrium

We have still a few things to learn in connection with the centre of gravity, and we will commence the

new operations with the help of this long narrow strip of wood.

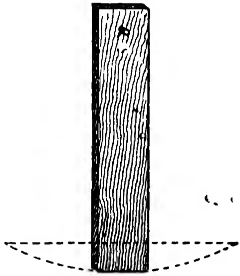
The oblong shape will at once suggest to you the position of its centre of gravity, for you know it must be in that spot where the two diagonals cross each other. Suppose we draw the diagonals and mark the spot.

You see I have drilled a hole through the wood at one end, and I will fix it to this upright board by means of a smooth French nail through the hole.



Now observe what happens when I move it round, so as to place it in an upright position, with the centre of gravity immediately above the nail, which forms the point of suspension.

I can with care adjust it so that it will balance itself on the point of suspension, but the slightest touch upsets the equilibrium, and it falls.



You notice too that, in falling from its original position, it sways to and fro before it comes to rest. But when it is at rest the centre of gravity is below the point of suspension, not above it.

If I move it in either direction from its present position, and then let go, it will return to rest or equilibrium each time, with the centre of gravity immediately below the point of suspension.

Notice, too, that, when I set it swinging to the right

or left, the centre of gravity is raised; but when it returns to equilibrium or rest, the centre of gravity is in the lowest position it can find.

A body in this position is said to be in stable equilibrium.

Let us place the strip of wood once more in the opposite position, with the centre of gravity above the point of suspension.

You observe that if I move it now to the right or left, the movement each time tends to lower the centre of gravity. The result of this is that it at once seeks the lowest position it can find, and comes to rest, or stable equilibrium at last.

A body whose centre of gravity is above the point of suspension will be upset at the slightest touch, and is said to be in unstable equilibrium.

If you test this for yourselves by suspending different bodies from the end of a cord, you will find that the centre of gravity in each case must be below the point of suspension, when the body is in equilibrium.

Let us leave these suspended bodies now, and turn our attention once more to bodies which rest on a base.

Take this cork and place it on the table, and you know it will remain at rest, on its side or on either end. The reason for that is clear, for its centre of gravity is in the middle of the line which joins the centres of its opposite ends, and the vertical line from this centre of gravity must fall within its base of support, in whatever position the cork is placed.

Now compare it with this other cork, which is loaded with lead at one end. I place this one with

its loaded end uppermost, and it will stand where it is, but the least touch will overturn it, and when once it moves it will not come to rest except on its leaden end. Every time I overturn it, the result is the

same; it will not return to equilibrium in any other position.

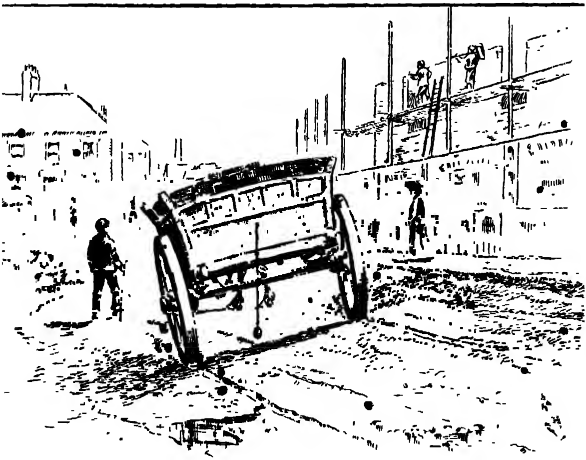
I think you can now easily reason this all out for yourselves.

Lead is much heavier than cork, and hence the heavy lead added to one end of the cork lowers the centre of gravity of the whole.

The consequence is that when we overturn the loaded cork, we raise for the moment the centre of gravity; and then the cork, left to itself, takes the first opportunity of returning to stable equilibrium, with the centre of gravity again at its lowest point.

Now let me give you one or two familiar illustrations of this.

Two carts are travelling along an unlevel road, the



one loaded with hay, the other with blocks of stone, or pigs of lead.

The haycart is easily overturned, because its centre of gravity is very high; but the other cart travels safely, because its load of stone or lead lowers the centre of gravity, and makes it more stable.

Then again picture a number of people in a rowing boat. As long as they keep their seats, the centre of

gravity of the whole remains in the lowest possible position, and all is well. But, as it so frequently happens, some of them get up suddenly, the centre of gravity is raised, and the boat is overturned.

Summary of the Lesson

1. The centre of gravity of a suspended body must be below the point of suspension, if the body is to be in stable equilibrium.

2. When a body is disturbed, its centre of gravity will always return to the lowest position it can find.

3. The cork loaded with lead will rest only in one position.

4 The lead, being heavier than the cork, lowers the centre of gravity of the whole mass.

Lesson VIII

Inertia

I want you once more to picture to yourselves the football field, with the ball lying on the ground between the two teams.

Of course it would remain exactly where it is for ever, if it were not acted upon by some outside influence, for it is dead helpless matter, and has no power in itself to move.

But let us now go a step further. Try to move some heavy box by kicking it, as you would kick the football, and you find that the box actually resists the force of the kick.

So does the football, for we can feel the resistance when we kick it; but in that case, the force of the kick is able to overcome the resistance, and the ball moves.

I carry you back to the football as a familiar illustration, because it may be taken as a type of all matter in this respect, for one of the properties of matter is that it has no power in itself to move. Even when a body falls to the ground, it does not move by reason of any power of its own. It is drawn to the earth, as you know, by the force of gravitation.

A body at rest resists any attempt that may be made to move it. It will never move in fact until force overcomes that resistance, and this you know for yourselves from every-day observation.

So far then we are clear on one point—that a body, of its own accord, never passes from a state of rest into a state of motion. Now let us look into the converse of this, and see how moving bodies are affected.

Picture the football in motion from the force of the kick. You know that after a time it begins to move more and more slowly, and at last comes to a stop. But you must also remember that the ball, being dead helpless matter, has no power in itself to change its state from rest to motion, or from motion to rest. Why then does it stop?

You will have no difficulty in telling me that the ball, as it rolls along, is acted upon by three opposing forces—the resistance of the air, the resistance of the ground, and the attraction of gravity. It is the result of these opposing forces acting on the dead helpless matter of the ball, which compels it to change its state from motion to rest; and this, I think, will be sufficient to prove to you that the ball does not stop of its own accord.

A cricket field, as you know, is always kept well rolled, to get rid of as much of the friction as possible,

because the ball will travel farther on a smooth surface than on a rough one. A billiard table for the same reason is frequently ironed to make it smooth, and the balls themselves are made of the smoothest ivory. You know too that your roller skates will carry you much farther on an asphalt road than on a rough one.

These are simple every-day facts, but they show you that the more those resisting forces are removed, the farther the ball will travel, and we are led to infer

that, if all the impeding forces of gravitation and resistance could be removed, there is no reason why the ball, or any other dead helpless matter, once in motion, should ever stop.

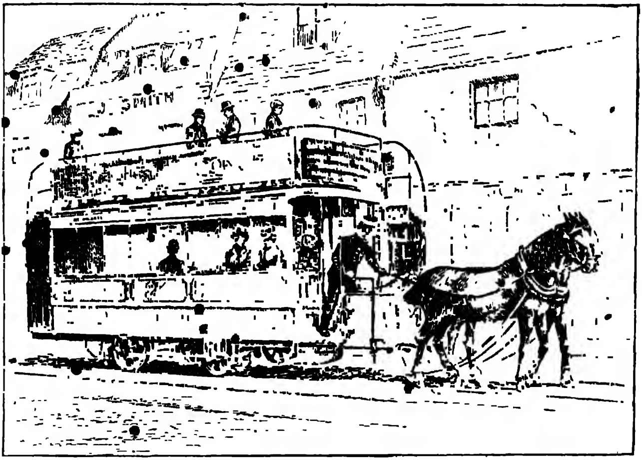
It would continue to move for ever, because such a body has no power in itself to change its state from motion to rest.

You are now clear, I think, on two important points, for you know that a body at rest will never

move till force compels it, and a body once in motion will never stop till force compels it.

This universal property of matter is known as inertia, and by virtue of it a body in a state of rest resists any attempts made to move it, and a body in motion resists any attempts made to bring it to a state of rest.

Let us take, as another familiar every-day illustration of all this, a tramcar at rest on the rails. It



cannot move of itself, and the tugging and straining of the horses prove that it resists any change from rest to motion. The horses, however, overcome the resistance—the inertia—and the car moves on.

It runs smoothly along the rails when once it has been set in motion, but it is clear that it now resists any change from motion to rest, for the driver, in order to bring it to a standstill, must apply a brake to the wheels to overcome the inertia.

Summary of the Lesson

1. A body at rest resists any attempt made to move it.
2. A body in motion resists any attempt made to bring it to a state of rest.
3. There is an inertia of rest, and an inertia of motion.
4. Neither body can change its state till force has overcome this resistance.

Lesson IX.

More about Inertia

You clearly understand now that inertia is that property by virtue of which matter resists all attempts to change its state, either from rest to motion, or from motion to rest. We ended up our last lesson with a familiar illustration from a tramcar, and of course precisely the same thing happens with a railway train.

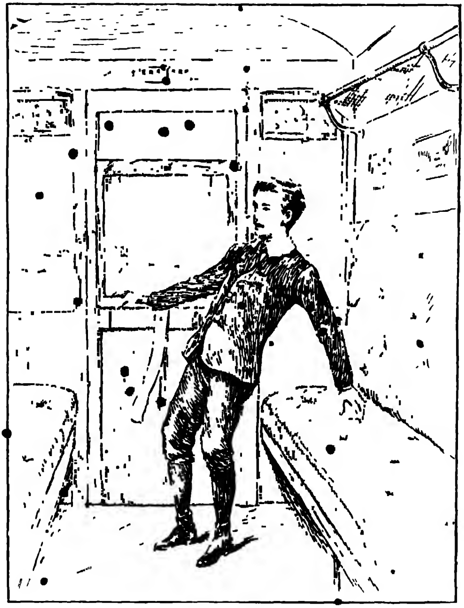
Imagine yourself standing up in the carriage, when the train moves out of the station, and tell me from your own experience, what happens.

What do you say? The sudden start forward throws you backward? Yes, you are quite right, and the reason is very simple. The motion of the train is first communicated to your feet, and they are carried forward. But the rest of your body resists the sudden change from rest to motion. Hence the upper part of the body is left behind, as it were; in other words it is practically thrown backwards.

Let us however picture to ourselves the same train at a later stage of the journey, when the driver applies

his powerful brake, and the train is brought to a sudden stop.

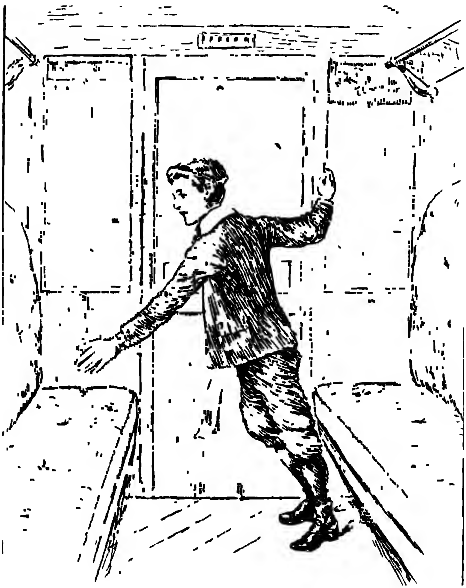
Ah! I see you have had some experience in this. Yes, you are quite right. The sudden stop throws you violently forward; but what is the cause of it all?



Your feet, resting on the carriage floor, stop suddenly with the train, but your body resists the sudden change from motion to rest. It continues its forward motion, and hence you are thrown forward.

The same thing happens when a cyclist comes to a sudden stop, a horse at full gallop stumbles, and a boat

sailing to land suddenly touches the shore. The cyclist is thrown forward over the handle-bars, the horseman is pitched over the horse's head, and the people in the boat are thrown forward—and in each case the result is due to inertia.



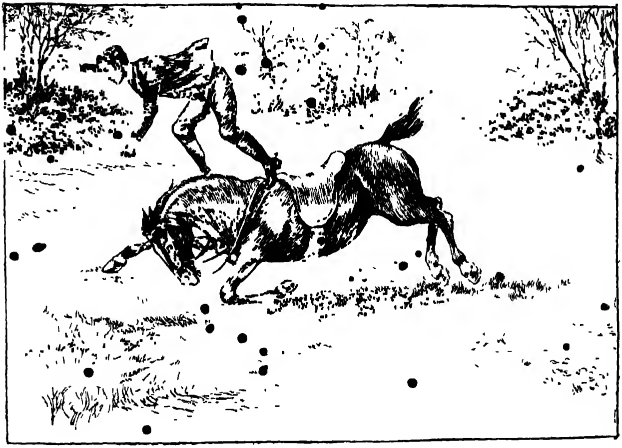
The cycle, the horse, and the boat, which are moving rapidly forward, come to a sudden stop; but the people themselves, who have been moving with them, resist the sudden change from motion to rest. They continue their own motion, and hence are thrown forward.

I cannot leave this subject without giving you a

word of advice about alighting from tram-cars and railway carriages in motion.

You must remember that when a person jumps out of a railway carriage in motion, his body has still the forward movement of the train, and it resists any sudden change from motion to rest.

But his feet coming into sudden contact with the platform or ground, bring the lower part of his body

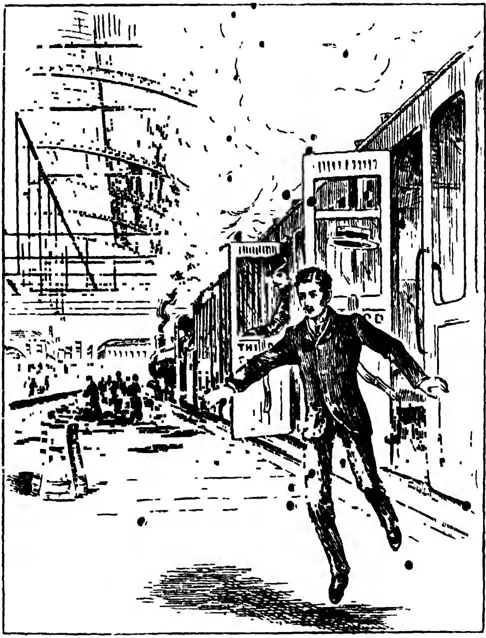


to a standstill, and the result is that the man is thrown violently forward on his face.

If, on alighting, you turn your face in the direction of the motion, and run along a few steps with the train, you will save yourself from a fall, for body and feet will thus gradually acquire the same velocity.

It is because of the numerous accidents that, passengers are always requested to wait till the train stops before attempting to alight.

While talking of railways, let us glance for a moment at the clever contrivance by which long-distance trains pick up water for their engine-boilers as they go along, for this is one of the practical appli-



cations of inertia, and depends for its accomplishment on the inertia of still water.

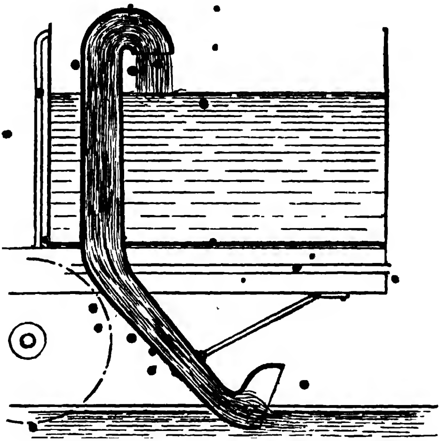
In a certain part of the line a long channel or trough, 18 inches wide and 6 inches deep, runs midway between the rails, and is kept filled with water, which of course is still, or in a state of rest.

The locomotive tender contains a large tank, and

leading from the upper part of this tank is a long hose, which dips down in a slanting direction into the water channel or trough.

The open mouth of the hose faces the direction in which the train is travelling, and as it moves onward it is constantly scooping up mouthfuls of water, so to speak.

This water, being at rest, resists at first the change to a state of motion, and before it has time to acquire

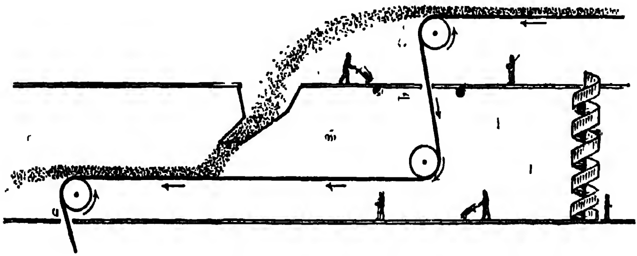


the forward motion of the train, more water is taken up by the scoop, only to act in a similar way. The result of this is that the inertia of the still water causes each mouthful to force the one before it up the scoop, and so into the tank.

The method employed in great granaries for transporting the grain from one part of the building to another is a most ingenious application of the inertia of matter in motion.

The essential part of the contrivance consists of a broad canvas band running on rollers, which revolve in opposite directions. Above the band is a shoot, down which the grain is allowed to fall; and the band, as it revolves, carries the grain along with it as far as the first roller.

But by this time the grain itself has acquired the motion of the band, and resisting any sudden change,



continues its onward course by its own inertia of motion, till it falls into another shoot, down which it slides to meet a second revolving band, and be carried forward in a similar way.

Summary of the Lesson

1. When a railway train starts suddenly, the passengers are thrown backward.

2. When the train stops suddenly, they are thrown forward.

3. Railway trains are able to take up water for their engine-boilers as they go along, because of the inertia of rest in the water itself.

4. Grain is conveyed from one part of a granary to another by the inertia of motion.

Lesson X

The Laws of Motion

Our recent investigations into the property of inertia have proved to us that a body at rest will never move 'till force compels it, and that the same body, once in motion, will never stop till force compels it.

You must also remember that all matter throughout the universe is subject to these two rules, and then you will readily understand why they are known as the Law of Inertia.

Sir Isaac Newton, after many years of patient investigation and experiment, discovered the existence of certain fixed and unalterable laws, which govern the movements of matter everywhere. These he named the Laws of Motion, and he took this law of inertia as the First of his Laws of Motion, embodying it as follows:—"Every material object remains in a state of rest, or of uniform motion in a straight line, until compelled by force to change that state."

Here we have practically our two rules condensed into a single statement; but you should clearly understand what is meant by uniform motion.

You know that the hands of a clock pass over equal spaces in equal intervals of time; and if you watch a revolving wheel, you will observe that it makes a certain number of revolutions in a certain time.

This is exactly what we mean by uniform motion, and the regular step of soldiers marching to the strains

of their band gives us another familiar illustration of the same thing.

Force acting on matter then compels it to change its state from rest to motion, or from motion to rest; but it often happens that two or more forces act upon a body at the same time, and we must now pass on to consider this, for it will lead us up to Newton's Second Law of Motion.

Picture a boat broken away from its moorings, and adrift on a river. You know that it will be carried down the stream by the force of the running water.

Then imagine a boatman in another boat on a wide canal, where the water does not flow in a stream, but is still. The man wants to get from one side of the canal to a point on the other side exactly opposite, and he simply turns the head of his boat in the direction of that point, and rows straight across.

You will observe that, in each case, the boat is acted upon by a single force; in one it is the force of the stream, in the other it is the man's muscular force.

Now imagine that the same boatman wants to cross a river to a spot exactly opposite his starting-point.

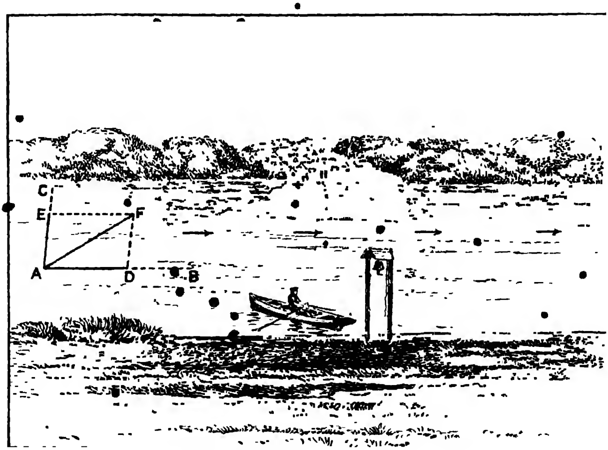
Instead of rowing straight across, as he did in the canal, he turns his boat's head against the stream, and rows up the river for some distance. Then he sets her head in the direction of the opposite shore, and rows straight across, and that will bring him to the spot he wishes to reach.

You will see at once that in this case there are two forces at work. The force of the running water urges the boat down the stream, and the man's muscular force is trying to propel it to the opposite bank.

Suppose, in the first place, the man had not used his oars at all. Then it is clear that the force of the running water would have carried the boat a certain distance down the stream.

But suppose again that the water had been still. In that case the boat would have been acted upon by the oars only, and they would have propelled it a certain distance across the stream.

Imagine the boat to have reached the point A in the river, and from that point measure off lines AD



and AE in the directions of these two forces, to represent the distances, through which each force would carry it. Then, if we complete the parallelogram ADEF, and draw its diagonal AF, that line will represent the direction of the boat's movement, as the result of the two forces which are acting on it.

The fact is, the force of the stream acting alone would have carried the boat from A to D, and the

force of the oars acting alone would have propelled it from A to E. When, however, the two forces act together, the one carries the boat the full distance down the stream, while the other is propelling it the full distance across the stream.

But it is clear that, no matter how many forces act upon a body, it can only move in one direction at one time; and therefore the boat does not move in the direction of either D or E, but midway between them, along the line AF.

This principle is known as the parallelogram of forces, and by it we can always find the direction which a body will take, when it is acted upon by two forces. We simply represent the direction of each individual force by a straight line, and make the length of the line proportional to the force. Then, if we complete the parallelogram, its diagonal will mark the direction which the body will take from the combined action of both forces.

It is important to bear in mind that, at the end of any given time, the boat is as far down the stream as it would have been had it obeyed the impulse of the running water alone, and as far across the stream as it would have been had it been propelled by the oars in still water.

This is the same as saying that each force has its full effect, and it will help us to understand Newton's Second Law of Motion, which says that, "if a body be acted upon by two or more forces at the same time, each force will produce its own effect."

Now, lastly, let us glance at the Third Law which says that "to every action there is always an equal and opposite reaction."

You will readily understand this, if you roll a ball along a smooth table, so as to make it strike against another ball, for you observe that, while it communicates motion to the second ball, its own motion is checked, as a result of the rebound, or reaction, between the two bodies.

The firing of a gun gives a familiar and forcible illustration of this same thing. The explosive force of the powder makes the projectile move forward in one direction, but the reaction of the projectile makes the gun itself rebound in the opposite direction, and the gun is said to kick, or recoil.

The projectile itself, being small in comparison with the gun, moves through a great space in the forward direction, but the equal recoil or reaction carries the heavy mass of the gun itself backwards.

Summary of the Lesson

1. The law of inertia is practically the same as Newton's First Law of Motion.
2. It says: "Every material body remains in a state of rest, or of uniform motion in a straight line, until compelled by force to change that state."
3. A body moves with uniform velocity, when it passes over equal spaces in equal intervals of time.
4. By the parallelogram of forces we can find the direction which a body will take when it is acted upon by two forces.
5. When a body is acted upon by two or more forces at the same time, each force will have its own effect (Second Law).
6. To every action there is always an equal and opposite reaction (Third Law).

Lesson XI

Falling Bodies

We have already learned that unsupported bodies fall to the earth, because the earth's force of gravity attracts matter of all kinds towards its centre.

You remember too that in our last lesson we found that all bodies in motion move by certain fixed rules, which we call the Laws of Motion.

Now, in this lesson it will be our province to deal with falling bodies, and we shall learn that, during their movement towards the earth, such bodies are subject to certain fixed laws of their own, just as other moving bodies are subject to the Laws of Motion.

Starting then from the well-known fact that all unsupported bodies fall to the earth we are at once reminded that some bodies are light, others heavy; some are large and bulky, others small and compact.

Then we naturally ask the question: "Do all falling bodies reach the earth in the same time?" Let us see.

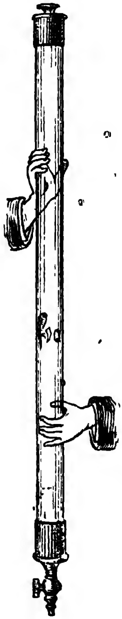
I have here two sheets of foolscap paper of exactly the same size and weight. One of them I roll up into a tight, compact ball, the other I leave spread out; and then I let both fall from the same height at the same instant. You observe that the rolled-up ball reaches the floor before the open sheet.

Here again are two leaden balls of exactly the same size and weight. I beat one of them out into a broad flat piece, but of course it is still the same

weight as the ball. Now if I let both fall from the same height, and at the same instant, the ball would reach the ground first.

All this leads us to believe that the weight of the falling body has nothing to do with the rate of its descent. Now let us go a step farther.

Sir Isaac Newton, to whom we are indebted for all we know on these matters, discovered by a clever experiment the laws which govern the movement of all falling bodies.



He provided himself with a glass tube two yards in length, one end of it being closed, the other fitted with a brass stop-cock. Then, after introducing into the tube a variety of bodies, such as pieces of lead, paper, and feathers, he exhausted the air from it by means of the air-pump, and closed the stop-cock. That done, he suddenly inverted the tube, and all the bodies in it fell from top to bottom in the same time.

Then he let in some air through the stop-cock, and again inverted the tube; and this time the pieces of lead reached the bottom first, and the paper, feathers, and things of that sort, fell later.

Newton in this way proved that gravity acts upon all bodies alike, and that the weight of the body does not affect its fall; the reason why one body takes longer to reach the ground than another being that it encounters more obstruction from the resistance of the air while it is falling.

This of course explains why, in our own experiments, the open sheet of paper and the flattened piece of lead took longer to fall than the round balls of paper and lead. The truth is, they offered more surface for the resistance of the air to act upon.

Newton, on making his discovery, formulated the first of the laws relating to falling bodies in these words: "All bodies fall with equal rapidity when free from the resistance of the air."

Now suppose we turn our thoughts for a moment to the moving cricket-ball or football. You know that in each case the ball is set in motion by a single impulse, and you also remember that, by the First Law of Motion, such a body, but for the resistance it meets with, would travel onward with uniform velocity for ever. That is to say, in one second it would travel a certain distance, in the next exactly the same distance, and so on during the next and the next for ever.

Let us compare this with the movement of a falling body, and you will see that when a body falls it does not move towards the earth by the force of a single impulse.

It is being constantly pulled or drawn by gravitation, and the nearer it gets to the earth, the greater is the force which gravity exerts on it. Hence a falling body does not move with uniform velocity, but with a constantly increasing velocity.

Scientific men have discovered by means of repeated experiments, that a body, which has been falling for a second, has acquired a velocity of about 32 feet; and the real meaning of this is that at the

end of the second it would be falling at the rate of 32 feet per second.

But the force of gravity does not stop with one impulse; it continues to act while the body is falling, and the same attracting influence which gives the body a velocity of 32 feet in one second, can do the same for the next, and for every second during the fall.

Hence the velocity at the end of the first second is 32 feet, at the end of the next 64 feet, at the end of the next 96 feet and so on, adding 32 feet for each second.

This discovery led Newton to formulate another Law as follows:—"The velocity acquired by a falling body is proportional to the time it has been falling."

I want you now to carefully consider the next step, for it will lead you to discover for yourselves the space through which a body falls in any given time.

We have already seen that the velocity of a falling body at the end of the first second is 32 feet; but when the body began to fall it was at rest, and therefore had no velocity at all. After once starting it gradually increases in speed till it moves at the rate of 32 feet a second.

Hence it is clear that, taking the whole second, its average velocity is 16 feet, or the half of 32 feet, and therefore the body during the first second falls through a space of 16 feet.

In continuing the fall for another second, the body commences with a velocity of 32 feet, and at the end of that second has reached a velocity of 64 feet, so that the average velocity for that second is the half of $32 + 64 = 48$ feet.

In other words, it falls through 48 feet during that

second, and in the two seconds it has fallen through $16 + 48 = 64$ feet of space.

On the same reasoning it has a velocity of 64 feet at the commencement of the third second, and at the end of that period it has increased its speed to $64 + 32 = 96$ feet. Therefore during that third second it falls through the half of $64 + 96 = 80$ feet, and through a space of $16 + 48 + 80 = 144$ feet in the whole three seconds.

Now, without going any farther, let us look at the figures for the three seconds. During the first second it falls through 16 feet of space, during the next through 64 feet, and during the third through 144 feet.

If we divide these figures—16, 64, 144—by 16 (the space through which the body falls during the first second), we get $1 \cdot 4 \cdot 9$; and we know that $1 \cdot 4 \cdot 9$ are respectively the squares of $1 \cdot 2 \cdot 3$.

It was from these figures that Newton evolved his Third Law relating to falling bodies, and he put it in the following words:—"The space which a falling body traverses is proportional to the square of the time it takes to fall."

If you ask your teacher he will continue the calculation on the blackboard, and you will then readily see from his figures that the space through which a body falls in any number of seconds increases as the squares of those seconds $(1)^2$, $(2)^2$, $(3)^2$, $(4)^2$, $(5)^2$, $(6)^2$, and so on.

Summary of the Lesson

1. Gravity acts upon all bodies alike.
2. The weight of a body does not affect its fall.

3. One body takes longer to reach the ground than another, because its fall is obstructed by the resistance of the air (First Law).

4. A falling body moves with a constantly increasing velocity.

5. The velocity acquired by a falling body is proportional to the time it has been falling (Second Law).

6. The space which a falling body traverses is proportional to the square of the time it takes to fall (Third Law).

Lesson XII

The Pendulum

The pendulum of a clock is really a very wonderful contrivance, and as it depends for its working upon several of the laws which we have recently been studying, it will be interesting and instructive to examine it now.

It consists of a round, lozenge-shaped piece of metal called the bob, suspended at the end of a long steel rod, the top of which is fixed to a thin flexible steel plate; and you know that it moves from side to side with a regular swinging motion.

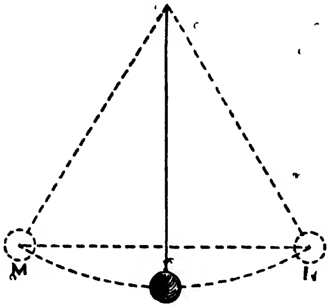
Any sort of weight suspended from a fixed point, so that it is free to swing, is really a pendulum; but the lozenge-shaped bob is preferred to a round ball, because its sharp edge offers less resistance to the air as it swings.

This ball and cord, which we used in our earlier lessons, will help you to understand the working of the pendulum.

If I fix one end of the cord to the gas-pipe, you know that the whole length of it will hang in a

vertical line with the ball at the other end, because the centre of gravity of the ball is then exactly below the point of suspension.

You know too that in this position the ball remains at rest, because the attractive force of gravity is neutralised by the resistance of the cord.



Now observe that each time it is moved aside from this position, so that the cord is no longer vertical, the ball itself is raised; and when it is let go, it falls back to its lowest point, like a ball rolling down a slope.

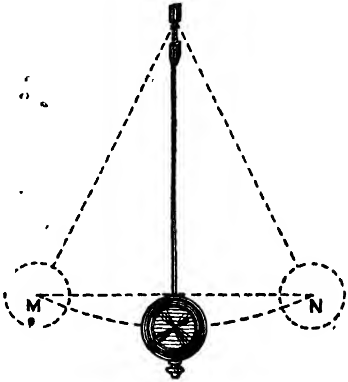
But it does not stop when it reaches this lowest point immediately below the point of suspension. It continues its onward course up the corresponding slope on the other side.

In fact, as it swings out of the vertical from side to side in this way, the ball describes the arc of a circle, and the extreme points of this arc are above the ball when it is at rest.

If you call to mind our experiments with the suspended strip of wood, you will remember that, when the centre of gravity of a body is raised, it always takes the first opportunity of returning to its lowest point, which is immediately below the point of suspension, for in that position alone can the body rest in equilibrium.

This is the whole secret of the real pendulum and its regular swing.

If I touch the bob of the pendulum, so as to make it swing, I observe that when it reaches the extreme end of the arc, it is raised, like the suspended ball, above the centre of gravity, and the force of gravity then compels it to fall towards its lowest point.



But during its fall it acquires a certain velocity, so that when it reaches its lowest point it does not stop, because the inertia of this acquired motion carries it onward in the same direction, till it reaches a point in the arc exactly opposite that from which it fell. Let us follow it in its movements by means of this sketch.

You will easily understand that, during its swing from its lowest point to N, gravity is exerting a retarding force on it, and is trying to pull it down; and the result of this retarding force, due to gravity, is to cause the bob to move more and more slowly.

When it reaches the point N it stops, because the inertia of motion has been overcome by the force of gravity and the resistance of the air, and here gravity compels it to fall once more, because it is raised above its lowest point.

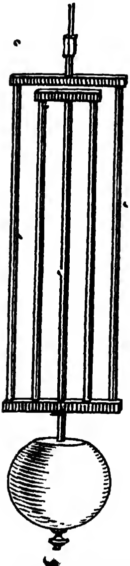
The inertia it acquires in its fall carries it back to M, but when it reaches that point, gravity once more compels it to fall, and so it goes on.

This swinging movement of a pendulum from side

to side is called an oscillation, and no doubt you have already observed for yourselves that one pendulum oscillates more slowly than another.

Yes, you are quite right: the tick of the clock marks the rate at which the pendulum swings; a long pendulum gives a slow solemn tick, a short one a sharper, more rapid tick. But we will leave the tick for the present.

It will be sufficient for our purpose to remember that by regulating the length of the pendulum, it is possible to make clocks which shall tick at any rate we please. Your teacher will no doubt explain[1] this more fully to you.



There is one point in connection with all this which we must notice here. As the length of the pendulum has such an important part to play in regulating the time of the beats, and therefore the whole working of the clock, it is absolutely necessary to prevent any variation in its length, because the slightest alteration in the length of the pendulum has the effect of making the clock go faster or slower.

You remember that metals expand and lengthen with heat, and contract and shorten with cold. In hot weather the metal rod of the pendulum is apt to become longer, and takes a longer time to make its oscillation, so that the clock loses; and in cold weather the reverse takes place and the clock gains.

[1] See corresponding lesson in *The Teacher's Manual*, in which this part of the subject is dealt with at length.

Hence in clocks which are to be subjected to variations of climate, a peculiar contrivance, known as the gridiron pendulum, is used. In this there are several rods instead of one. The outer ones are made of steel, and are attached to the top cross-bar; the shorter, inner ones are made of brass, and are attached to the bottom cross-bar.

The reason for this is evident. Brass expands with heat more than steel; the steel rods can only expand downwards, and the brass ones upwards.

In this way the expansions of the two metals are made to counteract each other, and the pendulum is kept at a constant length.

Summary of the Lesson

1. A pendulum swings by the action of gravity.
2. When it is moved from equilibrium its centre of gravity is raised.
3. It takes the first opportunity to regain its lowest point.
4. It falls back towards that point, like a ball rolling down a slope.
5. The inertia of motion carries it beyond that point and up the slope on the other side.
6. Gravity then asserts its power, and causes it to fall once more.
7. The gridiron pendulum is a contrivance for neutralising the contraction and expansion of the metal rod.

Lesson XIII

Clocks

It is an easy and natural step from the pendulum to the clock, because the whole mechanism of the

clock is governed by the pendulum. It will therefore be interesting and instructive now to examine the essential parts of an ordinary clock.

But before we do so let me remind you that, although the swinging pendulum, like the suspended ball, owes its start to the force of gravity, the same force of gravity tends to retard it and pull it back when, during its swing, it has passed its lowest point.

Then too besides this retarding force of gravity, it has to contend, during its journey to and fro, against the resistance of the air.

These two facts explain why the suspended ball, after oscillating for a time, gradually comes to a stop, and hangs in the vertical position at the end of the cord.

But the pendulum of the clock, when once it is set swinging, does not come to a stop; it continues its oscillations in regular rythmic order.

Why is this?

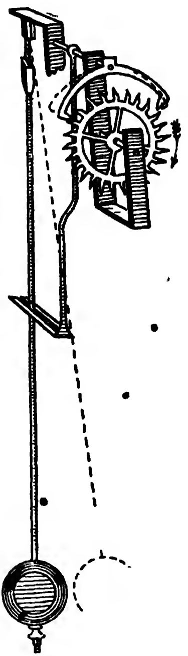
The heavy weight which hangs at the end of this cord will best answer that question, for it is another essential part of the clock.

The pendulum, you see, is swinging, and the clock is going regularly now; but observe what happens when I remove the weight from the cord.

As soon as this is done, the pendulum begins to shorten its swing from side to side, and at last it comes to rest in the vertical position, and then the clock stops.

Now note what happens when I attach the weight to the cord again, and give the pendulum a touch to set it in motion. The pendulum resumes its usual swing, and the clock starts working as before.

This is quite sufficient to prove that the weight, by some means or other, is able to counteract those opposing forces of gravity and resistance, so as to make them powerless to stop the pendulum. Let us see how this is brought about.



Without troubling yourselves very much about the intricacies of the wheel-work, you can easily unravel the whole mystery by examining the pendulum and its connection with the weight.

In the first place, then, you observe that the pendulum rod itself passes between the two prongs of a horizontal fork, and that this fork forms part of a vertical rod, which in its turn is fixed at its upper extremity to a horizontal axis.

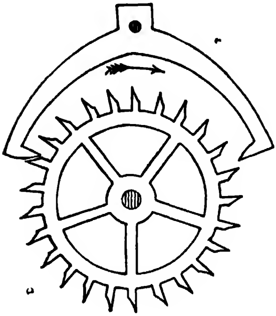
You will readily see, from this arrangement of the parts, that every swing of the pendulum must set in motion the fork, the upright rod to which it is fixed, and the horizontal axis above.

Then next you will observe that to one end of the horizontal axis is attached a flat piece of brass-work, having a projecting sort of tooth at each of its extremities. This is known as the escapement, and the projecting tooth or pallet at each end fits exactly into the spaces between the teeth or cogs of a wheel—the escapement wheel—immediately below it.

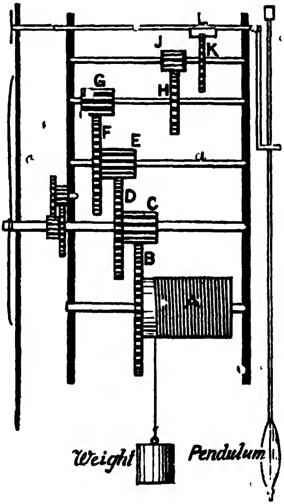
This escapement wheel is connected by a chain of smaller cog-wheels with a barrel or drum, and round

this drum is coiled the cord which supports the weight.

The weight is the actual moving power of the whole contrivance, for the force of gravity compels it to descend, and as it descends it causes the drum or barrel to revolve. But the revolving barrel transmits its motion to the escapement wheel, causing that also to revolve, and in this way the weight is made to act on the pendulum.



This description of the two essential parts should make the whole mechanism of the clock perfectly clear.



In the first place the swing of the pendulum communicates its motion to the fork, and so to the rod and the horizontal axis at the top.

Then the movement of this axis causes the escapement to work up and down; and at each movement the projecting tooth or pallet of the escapement fits into one of the spaces in the escapement wheel on that side, with a little clicking sound, which is spoken of as 'the tick of the clock.

This checks the movement given to that wheel by

the descending weight, until the pallet is raised on the return swing of the pendulum.

Then as the escapement wheel is released, it gives the pallet a slight push, and so conveys a new impulse to the pendulum, thus counteracting the retarding influences, and keeping the pendulum swinging at a uniform rate.

It is clear that if the escapement wheel has sixty teeth or cogs in its circumference, it will make one revolution for every sixty beats of the pendulum; and therefore if the pendulum beats seconds, the wheel will take sixty seconds, or one minute, to make its revolution.

All that is then necessary is, to fix a hand to the axis of this wheel, so that wheel and hand move together, and we are at once able to mark the seconds as they pass, for this of course is the seconds hand of the clock.

The rest is easy, for the other wheels of the clock are connected with this—the teeth of one wheel fitting into the spaces between the teeth of another.

The teeth of the wheel which carries the minute hand are so proportioned that, they move their wheel sixty times more slowly than that which carries the seconds hand.

Hence this wheel takes sixty minutes to make its complete revolution, and a hand fixed to its axis will point out the minutes as they pass. It is the minute hand of the clock.

The hour hand, in like manner, is fixed to the axis of another toothed wheel, whose teeth are so proportioned as to make it revolve twelve times more slowly than the last.

Summary of the Lesson

1. Gravity is a moving force, while the pendulum is falling down the slope towards the lowest point.
2. It becomes a retarding force as soon as the pendulum has passed the lowest point.
3. The pendulum in its movements has to contend against this retarding force, and against the resistance of the air.
4. The weight is attached to a drum or barrel, which is connected with the escapement wheel for the purpose of counteracting this resistance.

Lesson XIV

Light—Its Nature and Propagation

We have already had something to say about light as one of the Natural Forces, and you of course remember that it is the result of vibrations. The sun itself, the main source of all our light, is supposed to be in a state of rapid vibration among its particles, and this vibration is conveyed to the surrounding ether, and travels through it in waves.

Our next step will be to inquire into the nature and propagation of light.

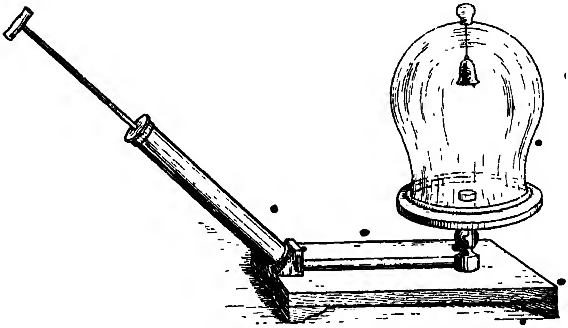
What do you say? Sound is also the result of vibration?

Yes, you are quite right; but there is a distinct difference between the two forces—light and sound—and this I will at once make plain to you with the help of the air-pump.

I have fixed a small bell to the roof of the receiver by means of a thread and some sealing-wax, and if I

give it a shake I can set the bell ringing. Now, if I exhaust the air in the usual way, and then shake the receiver again, you observe that although the hammer strikes the bell there is scarcely any sound. Indeed, if I could exhaust all the air, there would be no sound at all.

You can see the bell as clearly now as you did before the air was exhausted, but you get no sound. Hence it is plain that sound requires air for its propagation, but light does not require air.



Now let us pass on to inquire what this light is, and what it does.

You can see distinctly everything around you here, but if I took you into a dark cellar, every object in it would be invisible; and this is sufficient to prove that light is the external agent which produces in us the sensation of vision, and that without light there could be no vision.

This candle flame, you observe, is in a state of vibration; so too is this red-hot poker, which I have just taken out of the fire. These vibrations are conveyed through the surrounding ether in waves,

which at last strike on the retina of the eye, and enable us to see the candle and the poker.

We could see them in the darkest cellar, because they are self-luminous. But the great majority of objects are not self-luminous, and hence they are invisible in the dark. Even when we do see them, they become visible not by any light of their own, but by the light which emanates from luminous bodies.

If you hold a slate in front of the candle, the light from the flame cannot pass through it, and hence the candle is no longer visible to you.

Most bodies, as you know, such as wood, stone, metals, and so forth, are like the slate, and will not allow light to pass through them. They are said to be opaque.

But if you substitute a sheet of clear glass or a tumbler of water for the slate, the candle will be distinctly visible, for water and glass allow light to pass through them, and we say they are transparent.

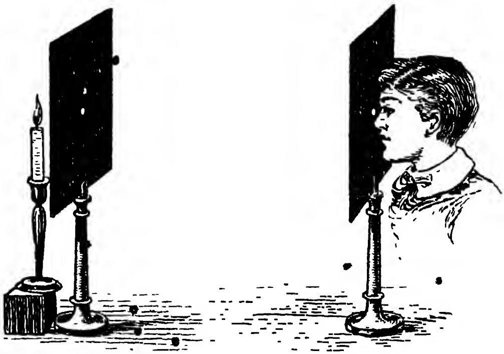
A sheet of oiled paper, a pane of ground glass, and a piece of thin porcelain would allow some light to pass through them; but not sufficient to enable us to distinguish the candle itself, and we call them translucent bodies.

Any substance through which light can pass is said to be a medium. Hence glass is a medium, and so is water. So also is the air itself, as well as the all-pervading ether which fills the boundless space beyond the confines of our atmosphere, for light travels through them from the sun to us.

I have here two sheets of card-board, which of course is an opaque substance, and you see I have bored a small hole through each of them. I will

stand both now in front of the candle in such a position as will leave the two holes in a line with the flame.

If you look through the hole in the second screen, you will see the flame distinctly, because it is in a direct line with both holes. But if I move either screen ever so slightly to the right or left, you cannot see the flame, for it is no longer in a line with the two holes.



The flame is still sending out its vibrations, for it can be distinctly seen through the hole in the other screen. The light passes through that hole in a direct line, but on reaching the second screen it falls on the card-board itself, and not on the hole; and as card-board is not a medium but an opaque body, the light will not pass through it. Hence the flame of the candle is not seen by a person looking through the hole in the second screen.

The result would be precisely the same if we moved the candle instead of the screen, for the flame would not be in a direct line with the two holes, and

the person looking through them would not see it, because light travels in straight lines.

If I stand a number of boys in a circle round the candle, the flame is distinctly visible to all, whatever position they may occupy, and this proves that a luminous body sends out light in every direction.

You remember, of course, that in one of our lessons on heat we hung a red-hot ball in the midst of a group of boys, and it was clearly proved that the heated ball sent out heat in straight lines, and in every direction. Do you remember what name we give to those lines of heat?

Ah! I thought you would remember that. Yes, we call them rays of heat, and we say that the heat passes away from the ball by radiation. In like manner light passes from luminous bodies by radiation, and the lines of light which emanate from them are called rays of light.

A collection or bundle of rays from the same source is called a pencil of light. If the rays which compose the pencil are all parallel, they are said to form a parallel pencil; but if they proceed from a point and separate from each other, they form a divergent pencil; and if they converge to the same point they are said to form a convergent pencil.

Summary of the Lesson.

1. Light is the external agent which produces in us the sensation of vision.
2. Light is the result of vibrations in the thin impalpable fluid called ether.
3. These vibrations travel through the ether in waves.
4. Self-luminous bodies are in a state of rapid vibration.

5. Non-luminous bodies become visible by the light which emanates from luminous bodies.

6. Any body through which light can pass is said to be a medium.

7. Light travels in straight lines.

8. These straight lines are called rays of light, and a bundle of rays is called a pencil of light.

Lesson XV

Light and Shade

Our investigations thus far into the nature and propagation of light have shown us that a luminous body sends out light in every direction, and that this light is conveyed by the vibrating ether waves in straight lines or rays, so that in this respect the radiation of light resembles the radiation of heat.

Now, before we proceed farther, let me give you a few startling facts in connection with light and its propagation.

We have already had occasion to notice the marvellous rapidity with which the ether waves vibrate, and you know from your own experience that there is nothing in Nature to compare for swiftness with a flash of lightning. Each flash comes so suddenly that there is practically no interval of time between its actual occurrence and its perception by the eye.

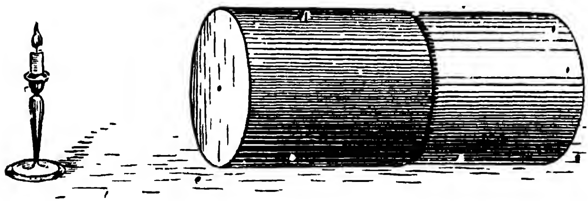
Light travels at the enormous rate of 185,000 miles a second, and such a distance, remember, would measure nearly 7½ times round our earth.

A cannon ball fired from one of our great guns moves with immense velocity, but it would take more

than 17 years to travel from the earth to the sun. Think of this, and then compare it with a ray of light, which travels the same distance in 8 minutes 18 seconds.

When I tell you that, the nearest of the fixed stars is 206,265 times the sun's distance from us, and that the light which we see from it, although it travels at the rate of 185,000 miles every second, has taken $3\frac{1}{4}$ years to reach us, you will perhaps form some idea of the immensity of the universe.

But there are some stars whose light, travelling



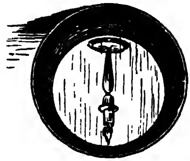
at the same rate, has taken thousands of years to reach this earth. Think of it, I say.

You already know that the rays of light always travel in straight lines. I will now show you a little experiment, which you can easily perform for yourselves at home, to prove this.

I have here a round tin canister from which the lid has been removed, and you see I have bored a small hole in the centre of the opposite end. You also see that the inside is blackened; I have smeared it with some of this lamp black.

Here I have too a card-board tube which fits into it exactly, and one end of this is covered with a cap of tracing paper.

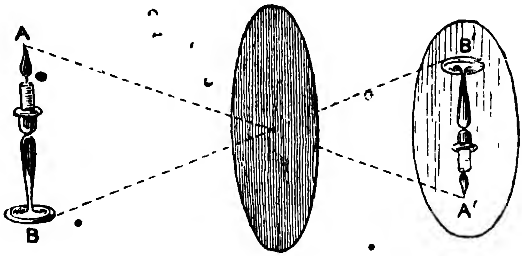
I will push this end into the open end of the canister, and then when I place a lighted candle in front of the pinhole at the opposite end, we shall get an inverted image of it on the tracing-paper cap.



The explanation is very simple after all, and perhaps the drawing below will make it simpler still.

In the first place you must remember that rays of light from the candle are sent out in all directions. Consequently a large number of these rays fall on the round end of the canister. But the canister is opaque, and no rays can pass through it, except in the one spot where the pin-hole is bored.

Let us trace the particular ray which proceeds from A, the topmost point of the flame, to the pin-hole. That ray passes through the hole, and falls on the screen at A′.



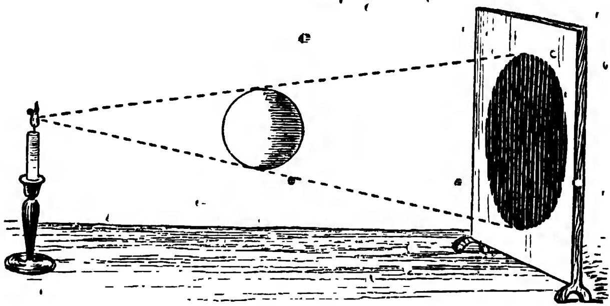
The point A′ on the screen is the image of the point A at the top of the flame. Similarly, if we trace the ray from B, it will, after passing through the pin-hole, form an image B′ on the screen, and cannot form any other.

Indeed, every ray from every point in the candle

between A and B, after passing through the hole, must have its image between A′ and B′, and in this way an inverted image is formed, because light can only travel in straight lines.

Let us now pass on to consider another result, which follows naturally from these special characteristics of light.

I hold this large ball in front of the candle-flame, and you know that rays of light from the flame fall upon the ball, but cannot penetrate it, because it is an opaque body.



You also observe that one half of the ball is lighted up, and the other half in darkness, and that the space immediately behind the ball is also in darkness.

That dark space is called the shadow, and it is dark simply because the rays of light from the candle-flame can only travel in straight lines.

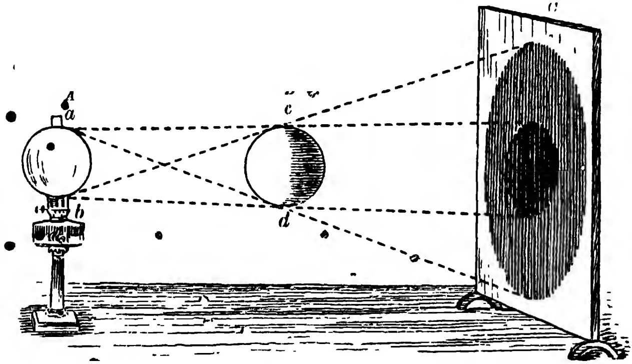
If I fix this sheet of white paper on the wall, I can catch the shadow of the ball on it, and that will help you to understand how it is formed.

The candle-flame is small compared with the size of the ball; indeed, we may regard it as a luminous point, from which a divergent pencil of rays falls upon

the side of the ball facing it, leaving the other side in darkness.

It is easy to see that the figure thus formed must be a cone, whose apex is the luminous point; and the base of the cone is the circular dark patch on the screen, or in other words the shadow which the ball casts.

I want you to note also that this shadow on the screen is sharply defined, and of equal darkness



throughout. That is always the case when the source of light is small.

We will now substitute the lamp for the candle, and I need scarcely point out that the source of light which it provides is much larger than that of the candle-flame.

I can catch the shadow of the ball which the lamp casts on the screen, as easily as I caught the other, but you observe that this time the dark circular patch is not equally dark throughout.

The inner part of the circle is very dark, but this is surrounded by a ring, which is only in partial

shadow. The very dark patch in the middle is called the umbra, the outer ring of partial shadow is the penumbra, and the two distinct shadows[1] are always formed when the source of light is large.

Summary of the Lesson

1. Light travels at the rate of 185,000 miles a second.
2. A ray of light from the sun reaches the earth in 8 minutes 18 seconds.
3. The light from some of the fixed stars has taken thousands of years to reach us.
4. The pin-hole image of the candle appears on the screen in an inverted position, because light can travel only in straight lines.
5. Opaque bodies cast shadows, because light cannot penetrate them.
6. The dark patch in the centre of a shadow is called the umbra.
7. The outer ring of partial shadow is the penumbra.

Lesson XVI

Reflection of Light

Let us commence to-day with a few simple experiments.

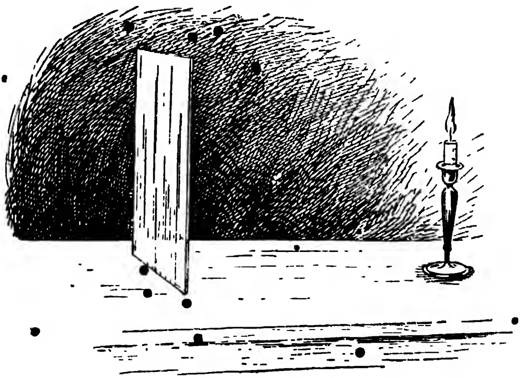
I place the lighted candle on the table, and stand a square of clear glass near it, in such a position as to enable you to see on both sides of the glass at once. Light, of course, is being radiated from the flame in every direction, and some of the rays must fall on the surface of the glass. Glass, you know, is a transparent

[1] This is more fully explained in the corresponding *Teacher's Manual.*

medium, and therefore those rays pass through it, and light up the things behind it.

I will now substitute this sheet of polished tin for the glass, and you observe that none of the rays pass through that, because tin is an opaque body. The space behind the tin is in dark shadow.

What becomes of the rays of light, which fall on the polished surface of the tin then? Ah! I see you have caught sight of the bright patch of light on the opposite wall, and that will answer the question.



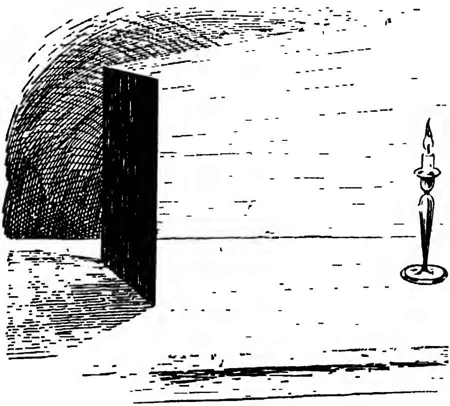
When a ray of light falls on a polished surface which it cannot penetrate, it is not lost or destroyed; it is thrown back in a new direction. This is known as reflection of light, and the body which reflects the light is termed a reflector. You remember that the heat rays from the fire are thrown back, or reflected, from the polished surfaces of the fender and fire-irons.

The light from our candle then, after falling on the polished tin, is thrown back, or reflected, and appears in a bright patch on the opposite wall. All polished

metals are good reflectors, but the best are the white silvery ones.

Here is a plate of ordinary looking-glass. See how brightly it reflects the light from the flame. It is simply a sheet of glass with a metallic coating of tin and mercury on the back.

It is the white metallic lustre on the back, and not the glass itself, which does the work of reflection. The glass is for the purpose of giving the metal a still



more highly polished surface. It improves the reflection, but is not the cause of it.

Now let me refer you to our lessons on heat, and you will no doubt remember that the heat-rays from any source of heat are absorbed, or reflected, by different bodies, according to the nature of their surface. A body with dark-coloured, rough surfaces absorbs more heat than it reflects; but a body with light-coloured, smooth surfaces reflects more heat than it absorbs.

You remember too that the heat, which is reflected in this way, is dissipated or scattered in all directions.

Practically the self-same rules hold good with rays of light. Opaque bodies absorb and extinguish some of the rays of light which fall on them, and reflect the rest.

A body with dark-coloured, rough surfaces absorbs more light than it reflects; but a body with bright-coloured, smooth surfaces reflects more light than it absorbs, and the more highly polished the surface, the better the reflection.

The light which is reflected is scattered in all directions, and is termed diffused light.

We have already seen that a luminous body, like the red-hot poker and the candle-flame, is visible by its own light. But the great majority of opaque bodies are not self-luminous—they have no light of their own. Such bodies become visible only by reason of the diffused light, which is reflected in all directions.

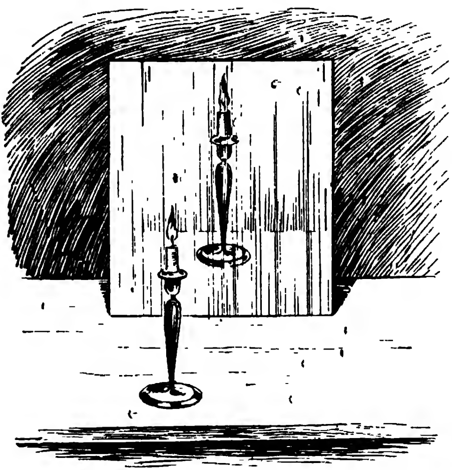
Hence it is clear that, when we look at a table, a tree, a flower, or any other object, it is the diffused light reflected on every side which enables us to see it; and the more diffused light there is, the more distinctly are such objects visible.

We look out of our windows on the surrounding objects, and they are all distinctly visible, for they receive and reflect plenty of light. But when we look in at the window from the outside, the interior of the room seems almost dark in comparison, and the objects in it are not distinctly seen, because they receive and reflect less light.

Let us now change the position of the looking-glass by standing it behind the candle. In this position

you are looking straight into the glass, and you now see the illusion of a similar candle behind the glass itself. This illusion behind the glass is also the result of reflection, and the reflex of the candle formed there is termed the image. You observe that the image is exactly similar both in form and size to the actual object.

When we speak of reflection, we generally have in



our mind the formation of an image by some reflector, and a body with a polished surface, which shows by reflection the image of an object placed in front of it is called a mirror.

Mirrors have been in use from very ancient times. You know that you can see your face reflected in the surface of still clear water, and it was probably that simple natural reflection, which first suggested to those ancient people the use of artificial mirrors.

Those early mirrors were made of polished metal—gold, silver, tin, and steel. But most metals tarnish in contact with the air; and hence in course of time an improvement was made, by coating a sheet of glass on one side with an amalgam of tin and mercury. The glass adds an extra polish to the natural lustre of the metal, and at the same time preserves it from tarnishing.

We shall have more to say about mirrors in the next lesson.

Summary of the Lesson

1. When light falls on a polished opaque surface, it is thrown back, or reflected.

2. White silvery surfaces are the best reflectors.

3. It is the metallic lustre on the back of a looking-glass which makes the reflecting surface.

4. Black, rough, unpolished surfaces reflect no light.

5. The great majority of objects are rendered visible by diffused light.

6. A mirror is a reflecting surface which shows the image of an object placed in front of it.

Lesson XVII

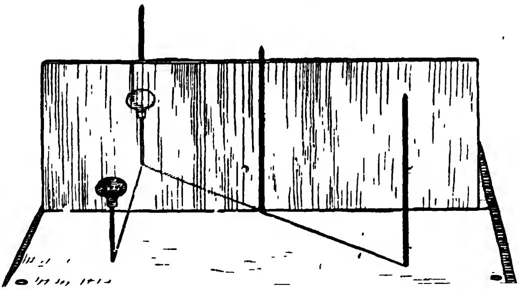
Mirrors

We have seen that reflection takes two forms—it scatters or diffuses light in all directions, and it produces an image of an object behind the polished surface. It is usual to speak of the formation of images as regular reflection, to distinguish it from the mere diffusion of light, which is known as irregular reflection.

Let us endeavour now to find out experimentally the reason for the name—regular reflection.

I will fix this sheet of drawing-paper on a large board, and lay it flat on the table, and then, after ruling a line across the middle of it from left to right, I will stand this strip of polished tin on the line, in an upright position, facing you.

That done, I stick a small brad-awl into the board at any spot on the paper to represent the object, and you of course see the reflected image of it behind the mirror.



The next step is to fix a sharp-pointed knitting needle at some spot on the pencilled line on which the mirror stands; and then to place a similar needle in such a position as to bring it into a direct line with the first one, and the reflected image of the object.

I will now draw on the paper a perpendicular to the mirror-line from the spot where the brad-awl stands, and then after removing the mirror altogether, I produce this perpendicular towards the far edge of the paper. You now observe that, if I join the holes

made by the two needles with a similar ruled line, and produce that line, it meets the perpendicular; and your ruler will prove by actual measurement, that the spot where they meet is exactly the same distance behind the mirror line, as the brad-awl itself is in front of it.

Let us mark this spot by fixing there another knitting-needle, and then if we replace the mirror, we observe that the image of the brad-awl seems to stand exactly where the needle is fixed. But we know the exact distance of that needle from the mirror, and therefore we also know the distance of the image, for it occupies the same spot.

The image of the brad-awl is as far behind the mirror, as the brad-awl itself is in front of it.

Now, if you place yourself in a line with the needles, you will be another step nearer the true solution. You see, in that position, the reflection of the brad-awl in the mirror, and the reflected rays which reach your eye proceed as if they came direct from the image at the back of the mirror; and that image, as you already know, is exactly as far behind the mirror as the brad-awl is in front of it, and in the same perpendicular line.

I will now remove everything except the sheet of paper, and I want you to notice the lines which have been drawn on it.

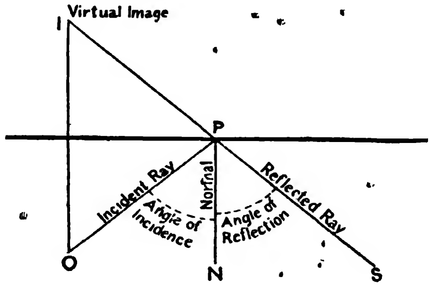
We will mark the position of the brad-awl by the letter O; then S shall represent the position of the spectator, I the image, and P the spot where the reflected ray from it crosses the mirror-line.

Then, if I join OP, and draw a perpendicular to the mirror-line from the point P, you will observe

(and can prove it by actual measurement) that the angles on either side of the perpendicular are equal.

Now for the explanation. The line PN, perpendicular to the mirror, is called the Normal; the line OP represents a ray of light falling on the mirror from the object, and is called the incident (or falling) ray; the line PS represents the same ray of light reflected from the mirror to the spectator's eye, and is known as the reflected ray.

For similar reasons the angle on one side of the



Normal is called the Angle of Incidence, and that on the other side the Angle of Reflection.

The rest is easy. The ray, which seems to come from the image behind the mirror, does not actually proceed from that spot. It starts from the object, falls on the mirror as the incident ray, and is thrown off towards the spectator as the reflected ray, and in every case of reflection the angle of incidence is equal to the angle of reflection.

This, of course, will be quite sufficient to explain the reason for the name—regular reflection. It is regular because it is governed by certain fixed laws.

Just one more thought in connection with the image itself. The reflected rays appear to proceed in a direct line from the image to the spectator's eye. But you know that this cannot be, for the light from the object cannot pass through the opaque mirror, and therefore cannot form any real or actual image there.

If we look behind the mirror we can see the needle, for it is actually there, but we cannot see the image of the brad-awl, because it has no real existence, although we can see it in the mirror itself.

The image which we see reflected in this mirror is only an optical illusion, and we speak of it as a Virtual image, because in reality there is no image behind the mirror at all.

Summary of the Lesson

1. In a plane mirror the image is as far behind the reflecting surface as the object is in front of it.

2. The rays of light from the object fall on the mirror, and are reflected back to the eye of the spectator.

3. The angle of incidence and the angle of reflection are equal.

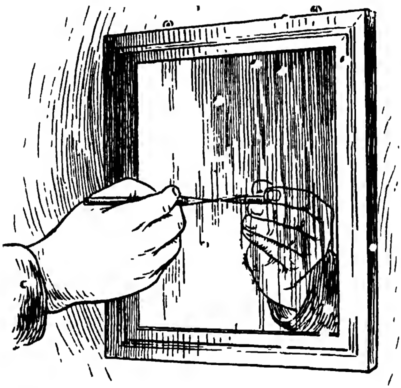
4. The image is a virtual one—a mere illusion—for it has no real existence.

Lesson XVIII

Some More Experiments

Our recent experiment with the mirror made it clear that the reflected image which we see is a virtual one —a mere illusion—and that it is as far behind the mirror as the actual object is in front of it. To-day we will have some further experiments in illustration of this.

Let us commence with a very simple one. I will merely touch the reflecting surface of this looking-glass with the point of my pencil, and while I hold it there, I want you to observe, in the first place, that there are two images of the pencil-point. The first, which is immediately behind the actual point of the pencil, is a very feeble image; but beyond that is a second and much more distinct one.

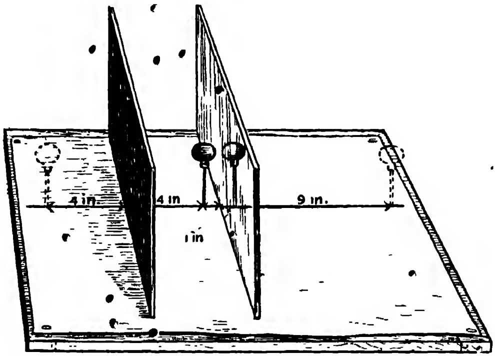


The feeble image in front is the reflection from the front surface of the glass itself; but the second and brighter image behind it is due to the reflection from the metallic coating on the back of the glass, and this is the one I wish you to particularly notice now.

The object, that is, the actual pencil-point, touches the glass, and therefore the distance between it and the reflecting coat at the back is the thickness of the glass, and you know that, by the law of reflection, the image must be exactly as far behind.

Hence it is clear that the distance between the object which touches the glass and the reflected image behind it must be twice the thickness of the glass, and this experiment is a simple test for ascertaining the thickness of a looking-glass.

Have you ever been in a room with looking-glasses on the two opposite walls? If you have, you must have been struck with the appearance of a long row of images of yourself, one behind the other, in each



mirror. Let us now inquire into the meaning of this.

In the first place, I need scarcely remind you that in such a position the mirrors which face each other are parallel; and if I stand these two looking-glasses on the table in the same relative position, with some object between them, you will have no difficulty in explaining the whole thing yourselves.

You know that the image formed by reflection is as far behind the mirror as the object is in front of it, and that the line between the object and the image is always perpendicular to the mirror itself.

That makes it an easy matter to locate the image behind each of the mirrors, for, after all, this is simply a matter of measurement along the perpendicular line.

When the exact spot is found behind each mirror, you may mark it as we did before with one of our knitting-needles.

You can see the knitting-needles of course, because they are actually there, but the image which you see by reflection in each glass is not really there, for you know it is a mere illusion—a virtual image.

But we have not done yet. There are other images extending one after the other in the same straight line behind each mirror. How are we to account for them?

Yes, I thought you would be sharp enough to tell that. The second image in the mirror on the right is simply the reflection of the first image in the opposite mirror; and in like manner the second image in the mirror on the left is the reflection of the first image in the other.

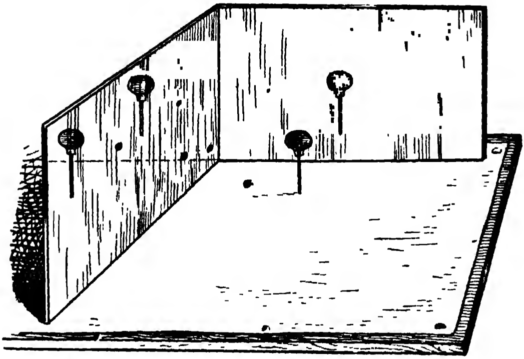
If you locate these as before with needles, you will find, too, that they are not at the same distances behind their respective mirrors, because each image must be as far behind the mirror as its object is in front of it.

We need not go any further, for every image in that long row is formed on exactly the same principle.

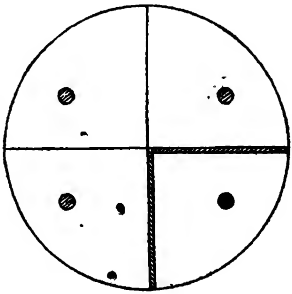
Now, suppose we change the position of the two mirrors by placing them at right angles to each other. Then if we fix the object, whatever it may be, at any point between the two, we shall always get three images of it and no more.

By virtue of the law of reflection there is an image of the object in each mirror, and that image is exactly as far behind the mirror, as the object is in front of it.

But the image itself in each mirror is again reflected in the other, the second image in either case



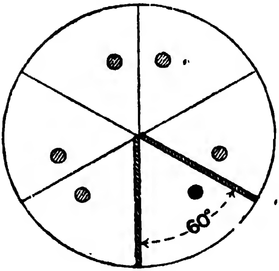
being exactly as far behind the mirror, as the original one is in front of it. The result of this is that these two second images coincide at every point, so as to form only a single reflection.



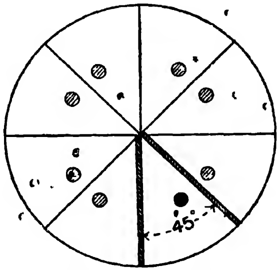
Hence it is that in two mirrors placed at right angles there are always three images.

If you draw a circle with two diameters at right angles, and make two of the radii represent the two mirrors, you will see it all clearly enough. The object stands between these two, and there is an image of it in each of the other three.

If we incline our two mirrors at an angle of 60°, we get five images of any object placed between them; and by drawing as before a circle with six angles of 60°, all meeting at its centre, you will see that the object stands in one, and that there is an image of it in each of the other five.



Similarly, and for the same reasons, the mirrors placed at an angle of 45° would give seven, and at an angle of 30° eleven images; because every image is exactly the same distance behind its mirror as the object is in front of it.



The Kaleidoscope is made on this principle, for it consists practically of three reflecting surfaces arranged at angles of 60° with each other, and the small pieces of coloured glass, falling into different positions in front of these inclined mirrors give rise to the changing forms we see, when we look through it.

Summary of the Lesson

1. A pencil-point touching the surface of a looking-glass gives two images.

2. One is a weak reflection from the front surface; the other a more distinct one from the metallic back.

3. Parallel mirrors give a succession of images one behind the other.

4. The first image in each mirror is a reflection of the object itself.

5. Each of the others is a reflection of the first or some other image.

6. Each image is as far behind the mirror as its object is in front of it.

7. Mirrors placed at right angles give three images of an object placed between them.

8. Mirrors placed at an angle of 60° give five images.

9. Mirrors placed at an angle of 45° give seven, and at 30° eleven images.

Lesson XIX

Curved Mirrors

All the mirrors we have dealt with thus far have been flat plates, and are known as plane mirrors: but we shall now turn our attention to some which have curved surfaces.

These curved mirrors are of two kinds. In one kind the inside, or hollow of the curve, is the reflecting surface, and these are known as concave mirrors. In the others the reflection is from the outside, or rounded surface, and they are called convex mirrors.

An ordinary curved watch-glass could be made to serve the purpose of either; for if it were silvered on the outside, it would make a concave mirror; and if the metal coating were laid on the inside, it would become a convex mirror.

Perhaps I can best make you understand the real nature of these curved mirrors with the help of this hollow india-rubber ball; and I will commence by cutting a circular piece out of it with my knife.

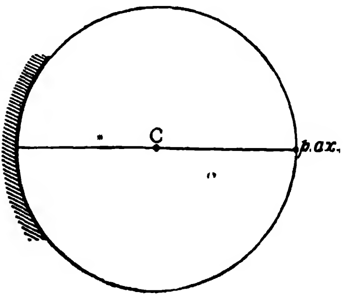
This piece of the ball, you see, is concave on one side and convex on the other. It was cut out of the ball; it is part of the ball.

We will now divide it into two equal parts by cutting it through the middle; and then if we cut the ball itself into two hemispheres, you can easily prove that the cut edge of either of the parts fits exactly the edge of the hemisphere wherever it is applied.

Of course you know that the edge of each hemisphere is a circle, and hence it is clear that this section, or cut edge of the small piece, is itself part of a circle.

If you understand this clearly, you will have no difficulty with the actual mirrors, for if either of them were cut through the middle, the section or cut edge would also be part of a circle, and we might represent it in a drawing like this.

It is at the same time perfectly clear that, as the curve of the mirror is really part of a circle, its centre is the centre of the whole circle. We shall henceforth call this the centre of curvature.



We will now bisect the arc which represents the mirror itself, and rule a line from the point of bisection to the centre of curvature. We shall frequently refer to this line, so you must try to remember its name—the principal axis of the mirror.

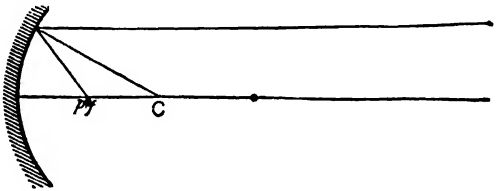
I now want to carry you back to one of our

earlier lessons. You no doubt remember that, if our india-rubber ball had been an immense one, say a yard across, a piece cut out of it the size of a sixpence would lie perfectly flat, although in reality it would be part of a spherical surface.

It is clear from this that the surface of every sphere is actually made up of an infinite number of very small plane surfaces.

You remember, too, from the same lesson that every line perpendicular to every one of these plane surfaces must pass through the centre of the sphere.

I think you will now readily understand from this that, as the surface of every curved mirror is



really part of a sphere, it is made up of an immense number of very small plane surfaces; that each of these is practically a little plane mirror in itself; and that every line at right angles to it must pass through the centre of curvature.

This sketch shows the section of a concave mirror, with its principal axis and centre of curvature marked. Let the dot in the corner represent a luminous point, from which rays of light are sent out in every direction, and the line from it parallel to the axis shall be one of these rays.

This ray strikes the mirror at a certain point, and if we join that point with the centre of curvature,

we know that the joining line must be perpendicular to the mirror itself at that spot.

Now if you turn your thoughts for a moment to the plane mirrors, you will remember that the ray of light which falls on the mirror at any spot is known as the incident ray, that the line perpendicular to the mirror at that spot is the normal, and that the angle of reflection is always equal to the angle of incidence.

Think of this, and you have the whole secret of the curved mirrors.

In our sketch a ray parallel to the axis falls on the mirror at a certain spot, and is the incident ray; the line from that spot to the centre of curvature is the normal; and if we make an angle on the opposite side of this line equal to the angle of incidence, the line which forms that angle will represent the reflected ray.

This ray, you see, cuts the principal axis exactly midway between the mirror and the centre of curvature; and the point where it cuts this line is known as the principal focus, because it is easily proved by experiment that, all rays which strike the mirror in a line parallel to the principal axis, intersect at that spot, after they have been reflected. We shall have more to say about these parallel rays in the next lesson.

Summary of the Lesson

1. Concave and convex mirrors are parts of spheres.

2. In a concave mirror the hollow side is the reflecting surface.

3. In a convex mirror the rounded bulging side is the reflector.

4. The centre of the sphere itself is the centre of curvature of the mirror.

5. The line from the centre of curvature to the middle point of the mirror is called the axis.

6. The principal focus is midway between the mirror and the centre of curvature.

7. All rays which strike the mirror in a line parallel to the axis are reflected to the principal focus.

Lesson XX

Concave Mirrors

In our last lesson we traced the reflection of a ray of light, which falls on one of these curved mirrors in a line parallel with its axis. But I want you now to clearly understand what is meant by such a ray.

In the first place, then, let me remind you that any pencil of rays, which falls on a mirror from a near luminous point, must be more or less divergent, because the rays spread out in all directions. It is equally clear that, as the distance between a luminous point and the mirror increases, the rays become less and less oblique. In fact, we may regard the rays from distant objects as practically parallel; they form a parallel pencil.

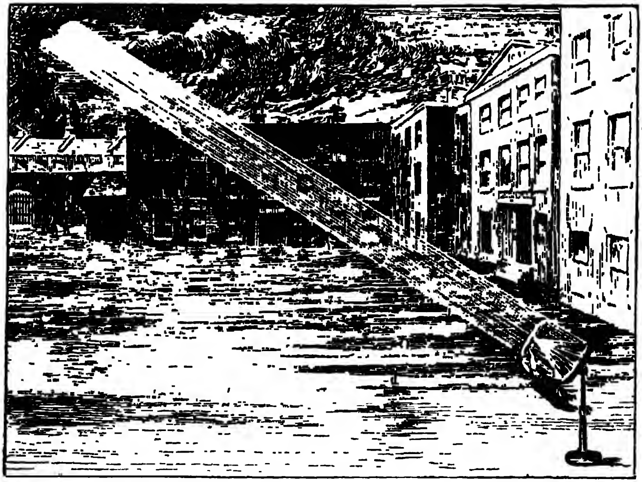
I have only to point out that the sun, and the other heavenly bodies which give us light, are separated from us by enormous distances, and you will at once understand that all the light they send us must fall in parallel pencils.

The sun is shining brightly this morning; so we will take our concave mirror out into the playground

for a simple outdoor experiment, which will make all this perfectly clear to you.

I will fix the mirror in a position where it may receive the direct rays of the sun. In such a position it is clear that, as the sun is shining full upon it, all the rays must be parallel to the principal axis.

Now I want you to carefully observe the next step. I hold this small piece of tissue paper some



little distance in front of the mirror, to act as a screen, and then slowly move it nearer and nearer.

You observe that, when the screen is in a certain position, a small, bright, luminous spot appears on it. This bright spot on the paper is the focus, to which all the rays of light from the mirror are reflected.

You already know that the sun's rays fall in parallel pencils, and that those which are now falling on the mirror are all parallel to its principal axis.

Therefore it is clear that the bright focus, which we see on the paper screen, is the principal focus of our mirror, for the rays of light which strike the mirror in a line parallel to its axis are reflected and meet there.

We have found the principal focus, you see, by experiment, and I think it will help you to understand more clearly all we talked about in the former lesson.

Before we go any farther, it will be well to measure with a ruler the distance of this principal focus from the lens. We shall find it useful later on, and besides that, if we know the distance of the principal focus, we have only to double it, and that gives us the distance of the centre of curvature.

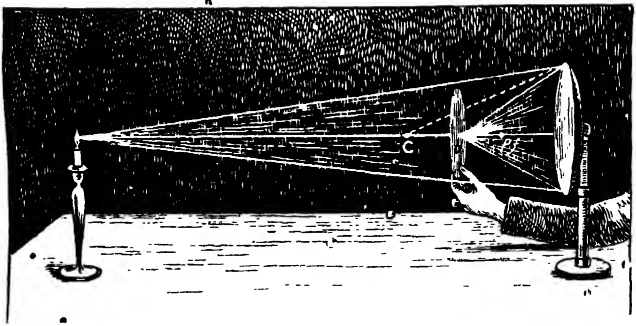
I may now point out that the very name, principal focus, seems to infer that these mirrors have more than one focus. Our next step, therefore, must be to find out how far that is true; and for this purpose we will return to the classroom and pull down the window blinds in readiness for another simple little experiment, which, of course, you can afterwards repeat for yourselves.

With the room then partially darkened in this way, I place the lighted candle on the table, and from what you have already learned you will easily understand that, the rays of light from it must fall upon all near objects in divergent pencils.

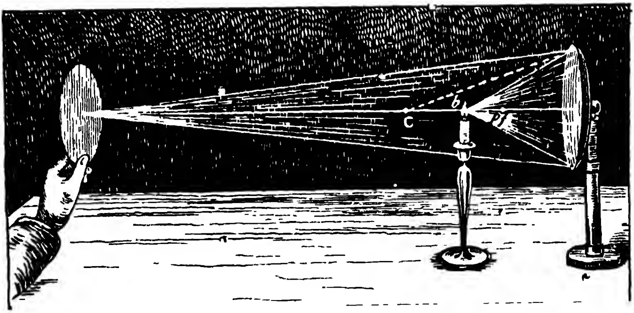
Therefore if I now stand the mirror a yard or so in front of the candle, it is clear that all the light which it receives from the candle must consist of the oblique rays of a divergent pencil. Having made that point clear, our next step will be to hold our tissue-paper screen between the two, and then move it slowly

towards the mirror until a position is found in which a bright, luminous spot appears on it.

This spot, of course, is the focus for the oblique rays of the divergent pencil of light which falls on



the mirror from the candle. Those rays are reflected by the polished surface of the mirror, and all of them



are concentrated on this one spot, which thus becomes their focus.

Now observe what happens when we reverse the positions by standing the candle in this focus, and

holding the paper screen where the candle itself originally stood.

The rays from the candle still fall on the mirror in a divergent pencil, and are reflected as before; but this time they come to a focus—a single luminous spot—on the screen in its new position.

It is evident from this that in each case the luminous object and its focus are so connected that they can exchange places. We say that each of these points is the conjugate focus of the other, and the name conjugate comes from a Latin word which means connected. The name conjugate focus is employed to distinguish this one from the principal focus, to which all parallel rays are reflected.

Now before we go any farther, let us gather up what we have learned so far.

We know that all rays which strike a concave mirror in a line parallel to its axis are reflected to the principal focus, and actually pass through the principal focus, so that they can be caught as a luminous spot on a screen.

We know, too, that rays which strike the mirror obliquely from some luminous spot, and are reflected to its conjugate focus, also pass through that focus, and can be caught on a screen.

Because the reflected rays can be actually caught as a luminous spot on a screen, the focus in each case is said to be a real focus.

Now let us place the candle a few inches only from the mirror, and again take our observations. The rays from the candle this time strike the mirror, and are reflected as usual; but instead of being gathered together after reflection, they are dispersed, and can

never form a real focus—a luminous spot which may be caught on a screen.

As we look into the mirror we see a reflection of the light, as if it came from a point behind the mirror. But we know that none of the light can actually pass through the mirror to reach that point, and that the reflection is only an illusion. We therefore call this a virtual focus to distinguish it from a real focus.

Summary of the Lesson

1. Rays of light from a near object are more or less oblique.
2. They become less oblique as the distance increases.
3. Rays from distant objects form a parallel pencil.
4. The sun's rays always fall in parallel pencils.
5. Every pencil of light from the sun falling on a concave mirror is reflected to the principal focus.
6. Oblique rays are reflected to some other point, which is called the conjugate focus.
7. Rays from a luminous spot between the principal focus and the mirror have their focus behind the mirror, not in front of it. This is a virtual focus.
8. A real focus is one which can be caught on a screen.

Lesson XXI

Images formed by Curved Mirrors

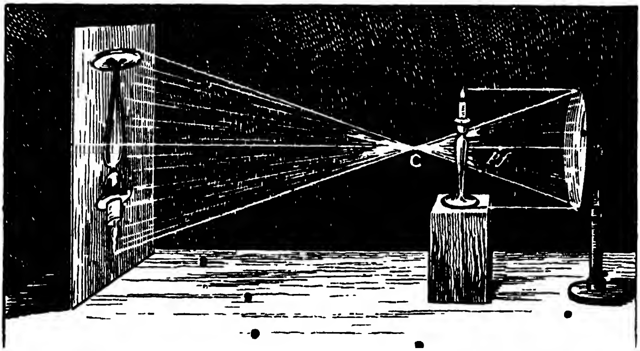
In our recent experiments with the concave mirror we found that, when the rays from a luminous spot fall upon the mirror and are reflected back from it, they may be caught on a screen, where they all meet in a bright spot, which is called the focus.

This focus, or bright spot which appears on the screen, is in reality the image of the original luminous spot, and it is said to be a real image, because the reflected rays actually pass through it.

In each of those experiments we purposely confined our attention to the reflected image of the one luminous spot. But it is important to remember that every point in every object placed before the mirror has its image, and that it is the reflection of all these points, which produces the image of the whole object.

Let us now turn our attention to the formation of images, commencing as before with those formed by concave mirrors.

We will pull down the blinds, to partially darken

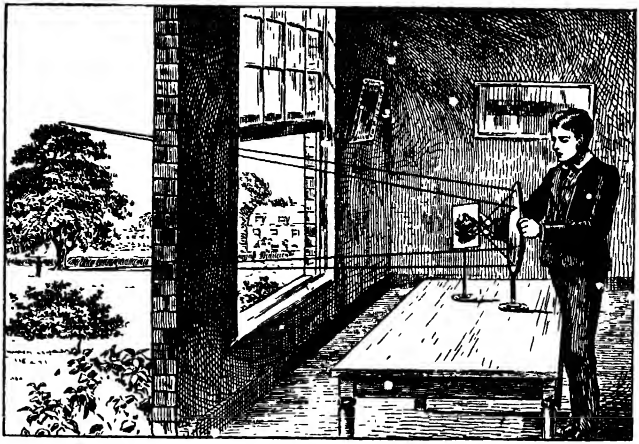


the room as usual, and then place a lighted candle in front of the mirror at some spot between the principal focus and the centre of curvature. You remember we have already found the distance of both these points, so we can easily locate them with the help of the ruler.

I will now hold the paper screen on the farther side of the candle, and move it slowly backwards, until a position is found in which a distinct image of the candle appears on it.

You observe that the image is inverted, and larger than the object itself, and you also see that the image is much farther from the mirror than the object is.

Let us now raise the blinds, open the window, and place the mirror in front of some object outside, on which the sun is shining. Then, if I hold the paper screen a little on one side of the mirror, and move it



slowly, I shall at last find a position in which a distinct image of the object will appear on it.

The image, you observe, is inverted as before, but in this case it is very much smaller than the object; and I need scarcely say that this time the image is very much nearer the mirror than the object is.

These two experiments will be sufficient to show you that real images formed by concave mirrors are always inverted, and that the size of the image bears the same proportion to the size of the object, as the

distance of the image from the mirror bears to the distance of the object from it.

You can prove all this for yourselves in a very simple way. If you hang the mirror on the wall, and stand two or three yards away from it, you see as you walk slowly towards it an image of yourself reflected

in its surface; but, instead of being life-size and erect, as it would appear in an ordinary looking-glass, it is inverted and much smaller.

But if you continue to advance slowly towards the mirror, you will also observe that as you get nearer and nearer to it, the image increases in size, although it is still inverted.

The fact is, every step you take lessens your distance (as the object) from the mirror, and increases the distance of the image from it; and then the rule comes in that, the size of the image is to the size of the object, as the distance of the image is to the distance of the object from the mirror.

It is worthy of note that, all this time, as you continue to advance towards the mirror, if some one holds the paper screen in front of it, a distinct inverted image of yourself will appear on the screen, and it will gradually increase in size as you get nearer. This, however, is exactly what you would expect, for you know that these are all real images.

But suppose you continue to advance towards the mirror in the same slow manner. You will at length reach a certain point where the reflection in the mirror will disappear entirely, and it will also be impossible to catch any image on the screen.

If at this spot you measure your distance from the mirror, you will find that you are in the principal focus; and just as parallel rays when reflected by the mirror converge to this point, so all rays from the principal focus, when reflected, proceed in parallel lines. Such lines, of course, can never meet; they can never form a focus, and therefore there can be no image.

Summary of the Lesson

1. When an image can be reflected on a screen from a concave mirror, it is said to be a real image.

2. When a person looks into a concave mirror a little way off he sees a small, inverted image of himself.

3. This is a real image; it can be caught on a screen.

4. An object in the principal focus of a concave mirror cannot produce an image.

Lesson XXII

Virtual Images in Curved Mirrors

You remember that I left you standing in the principal focus of our concave mirror, and that when you looked into the mirror from that position you saw no reflection of your face in it.

You had been slowly advancing towards the mirror till then, and as you advanced you saw a distinct inverted image of yourself in it; but the moment you reached the principal focus the image disappeared like magic, leaving the mirror a blank.

Suppose now you once more take up your position a little distance in front of the mirror, and move slowly towards it as before. As you continue to advance, you see distinctly your inverted image in the mirror, till all of a sudden it disappears, and then you know you are in the principal focus again.

I have gone over this ground a second time, because we shall make the principal focus our starting-point to-day, and I want you now to continue your slow advance from it towards the mirror.

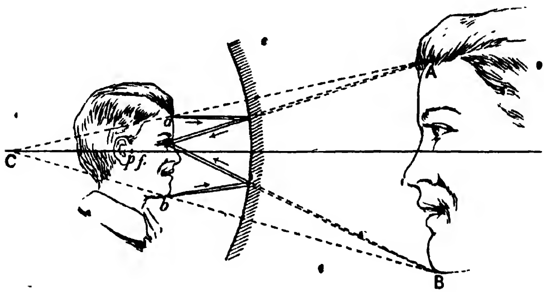
You observe that as soon as you begin to move forward from the principal focus, the image reappears in the mirror. But it is no longer an inverted image, it is now erect and greatly magnified, and the nearer you get to the mirror the larger the image becomes.

Now let us see what we can make of this with the help of a sketch. I will first draw a section of the mirror itself, with its axis, principal focus, and centre of curvature all duly marked. Then I will

draw your face in profile looking into the mirror between it and the principal focus.

That done, let us imagine that a ray from some part of your face—say your forehead—strikes the mirror at a certain spot. That ray must obey the laws of reflection, and it will in consequence be reflected back to your eye.

The result of this is that you yourself see the reflected image of that particular spot, *a*, on your forehead, as if it came from behind the mirror at A, where



the reflected ray, if produced, would meet the line from the centre of curvature.

We might, of course, deal in the same way with other imaginary rays from various parts of the face—ears, nose, chin, and so forth—and it would be an easy matter to show that each point has its reflected image behind the mirror.

You remember, no doubt, that in one of our experiments, when we placed a luminous point between the mirror and its principal focus, the reflected image of it appeared to come from a point behind the mirror, and was proved to be a virtual image — a mere

illusion—because the mirror itself is an opaque body, and light cannot penetrate it.

Hence it is clear that the images of all those points in your face, which appear behind the mirror are in like manner mere illusions, or virtual images.

But as every point in every object placed before a mirror has its image, and the reflection of all these

points forms the image of the whole object, therefore it is evident that the erect, enlarged image of your face, which you now see in the mirror, is only an illusion—a virtual image.

Let us now pass on to deal in a similar way with the convex mirror and the images it forms. This mirror, as you know, reflects light from its rounded or

bulged side, and not from its hollow surface, as the concave mirror does.

We will commence by hanging it on the wall, and you shall tell me what you observe, as you advance slowly towards it from the opposite side of the room.

Yes, you are quite right; you see a small upright image of yourself reflected in the mirror, and as you

approach nearer and nearer, the image increases in size. But the image is always erect, and always smaller than the object.

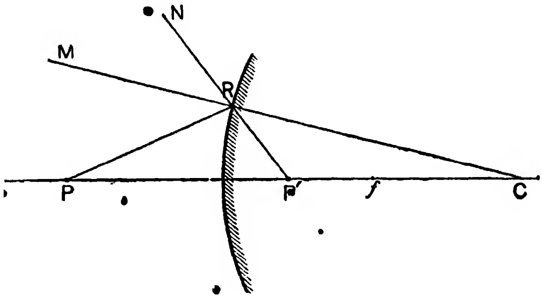
Let us see what else we can learn about it with the help of this drawing.

In the first place, then, as the rounded face of this mirror is its reflecting surface, it is clear that the

centre of curvature and the principal focus are behind the mirror, not in front of it.

Suppose P is some luminous point in front of the mirror, and PR represents a ray of light from it falling on the mirror at R. Then if we join R with C, the centre of curvature, and produce the line to M, we shall have the normal RM, and of course RN will represent the reflected ray.

Needless to say, such a ray could never come to a focus, but if the line is produced backwards it meets



the principal axis in P′, and that point is the image of the luminous point P. But as it is formed behind the mirror it is only an illusion—a virtual image.

Let me in conclusion once more remind you that what is true of a single ray from any single spot is equally true of the entire object. Hence it is clear that the image of yourself which you see in a convex mirror is a virtual one.

Summary of the Lesson

An object in the principal focus of a concave mirror cannot produce an image.

2. When a person looks into a concave mirror a little way off he sees a small, inverted image of himself.

3. This is a real image; it can be caught on a screen.

4. As the object approaches close up to the mirror, the image appears erect and greatly magnified.

5. This one is a virtual image; it is formed behind the mirror; it cannot be caught on a screen.

6. The image reflected in a convex mirror is always erect, and it increases in size as the object approaches nearer.

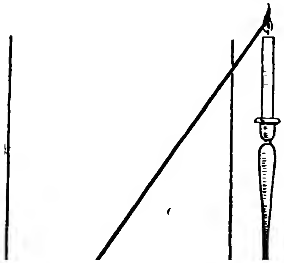
7. It is formed behind the mirror, and is therefore a virtual image.

Lesson XXIII

Refraction of Light

You already know that light passes through some bodies but not through others, and that because of this every transparent body, such as air, water, and glass is said to be a medium.

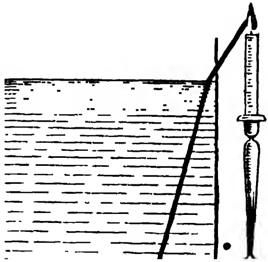
Till now we have confined our attention to the passage of light through one medium only—the air around us, and we have found that light always travels through the air in straight lines. Our next step is to learn how a ray of light acts, when it passes from the air into some other transparent medium, such as water.



I have here a large square biscuit box, with a little hole pierced in one side of it near the top. We will pull down the blinds, and stand the lighted candle a short distance from the hole, and

then you will observe that there is a small circle of light on the floor of the box. The light from the candle, of course, proceeds in straight lines through the hole, and falls on that spot.

I will now fix this bright new threepenny piece on the circle with sealing-wax, and fill the box with water almost up to the hole. When that is done you will observe that, although the coin remains where it was placed, the circle of light is now seen some distance in front of it.



The fact is, the light from the candle proceeds as before in straight lines, till it meets the surface of the water; but at that point it passes into another medium which is denser than the air. That denser medium bends the rays of light out of their straight course, and we say the light is refracted.

I will now pour away the water, leaving the coin on the original spot, and you shall look at it through the small hole.

You see the coin, because rays of light proceed from it in straight lines, through the hole to your eye.

But observe what happens when I fill the box with water again. You cannot see the coin at all through the water now, although it still remains where it was first placed.

I will drop this small bright button into the water, and move it forward gradually with a stick, while you are still looking through the hole. Presently as

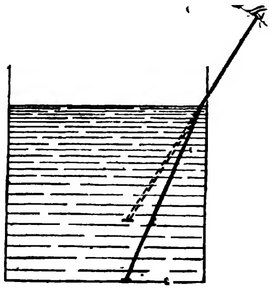
I move it forward, it becomes visible to you, but it is now some distance in front of the coin, which you cannot see at all.

The explanation is simple. The rays of light from the button proceed in straight lines through the water, and it is quite clear from this sketch that, if they continued in that direction, they would pass above your eye, as you look through the hole.

But at the surface of the water they enter a new medium—air, which is less dense than water, and on entering this they are bent out of their straight course, or refracted. It is the refracted light which reaches your eye, and enables you to see the button itself at the bottom of the water.

You will clearly understand from these experiments that light is always refracted, or bent out of its course, when it passes from air into water, which is a denser medium, and also when it passes from water into air, which is a less dense medium.

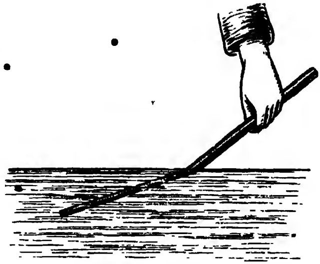
Let us turn to our sketch once more. The refracted rays, which proceed from the surface of the water to your eye, and enable you to see the button, actually come from the button at the bottom of the water. But to you they appear to come from a spot above it, which is the refracted image of the button, and not the button itself.



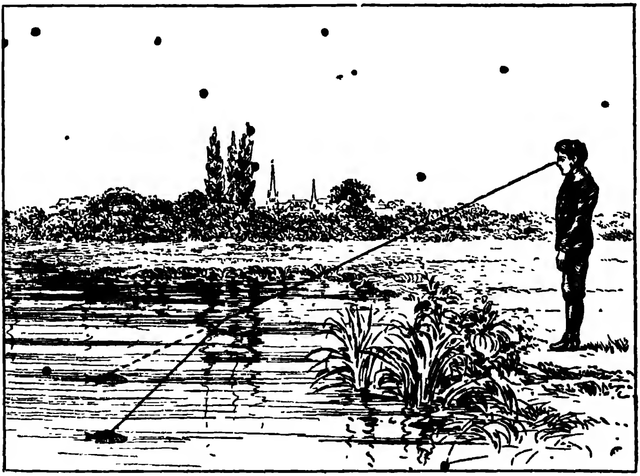
This image is only an illusion, and is the result of the refraction of light, which appears to raise the floor

of the box, and with it of course the button itself, so as to bring it within the line of sight.

Hold this stick obliquely in the water, and you will get a capital illustration of what I mean. The part of the stick out of the water is seen of course in its true position, but the part in the water appears by refraction to be raised, and that gives the stick itself a broken appearance at the surface of the water.



If you hold the stick upright in the water, and look at it from above, it appears shorter than it really

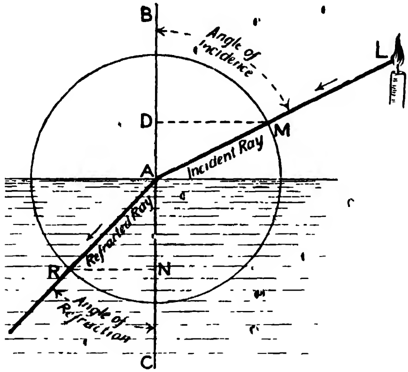


is; and for the same reason, when we watch the fish in a pond, we do not see them in their true position, but

higher than they really are. We see the image of the fish caused by the refraction of light—not the real fish.

For the same reason, again, the pond itself is much deeper than it looks to be. The bottom which we see is only about three-fourths of the real depth; it is an illusion—the raised image of the actual bottom, and this fact should never be lost sight of by young bathers, especially in strange water.

In conclusion I may state that refraction, like



reflection, is governed by its own unalterable laws, which your teacher will no doubt explain to you in class. It will be sufficient for our purpose here, if I put those laws into simple language, which you can remember.

But to do this I must take you back to our sketch of the candle shining on the water through the little hole in the side of the box, and at the point where the rays from the candle fall on the surface of the water we will draw a perpendicular. This perpendicular we

shall call by an old familiar name, the normal, and all I want you to remember here in connection with it is that whenever refraction takes place, the ray of light is bent towards the normal in passing into a denser medium, but from the normal in passing into a rarer medium. The sketch itself will show you this.

Summary of the Lesson

1. Every transparent body is said to be a medium.
2. Water is a denser medium than air.
3. When a ray of light passes from one medium into another, it is bent out of its straight course. We say the light is refracted.
4. A stick held obliquely in the water appears to be bent upwards.
5. The same stick held upright in the water appears shorter than it really is.
6. We see the image of a fish—not the fish itself—in the water.
7. The bottom of a pond is much deeper than it seems to be.
8. The refraction of light is subject to fixed rules, which are called the Laws of Refraction.
9. The refracted ray is bent towards the normal in passing into a denser medium.
10. It is bent away from the normal in passing into a rarer medium.

Lesson XXIV

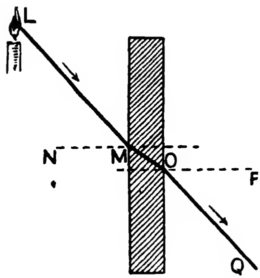
Glass as a Medium

Our experiments in the last lesson dealt with the passage of light through water. Let us now endeavour to find out what happens to rays of light in passing through glass, which is a denser medium than water.

Here is a piece of thick plate-glass. We will commence with that, and I may point out (although, of course, you can see it for yourselves) that its opposite faces are parallel.

Let us begin then by making a sketch of a section of it, with a lighted candle close by, and we will imagine a ray of light LM from the candle falling obliquely on the glass at M.

That done, you will have no difficulty in telling me that the perpendicular at M is the normal, and that the angle LMN is the angle of incidence.



Then you have only to call to mind the rule with which we ended up our last lesson, and the whole secret lies open before you.

The ray, you know, is bent towards the normal in passing from any medium into a denser one, and it is therefore an easy matter to show on the sketch the direction which the refracted ray must take.

But this same refracted ray, after reaching the point O on the opposite face of the glass, must pass out from a dense into a rarer medium. If then we erect another perpendicular—or normal—at the point O, our twice-refracted ray will make with it an angle POQ equal to the angle LMN, because the refracted ray OQ is bent away from the normal this time.

We learn from this that a ray of light, which strikes a sheet of plate-glass obliquely, is bent towards the normal; and that when it emerges into the air

again on the opposite face of the glass, it is bent away from the normal by exactly the same angle.

The result therefore is that, this twice-refracted ray emerges from the glass in a direction parallel to its original direction, so that practically it proceeds in the same straight line.

It should be borne in mind, too, that every ray at right angles to the surface of the glass is itself normal, and of course passes directly through the glass without refraction.

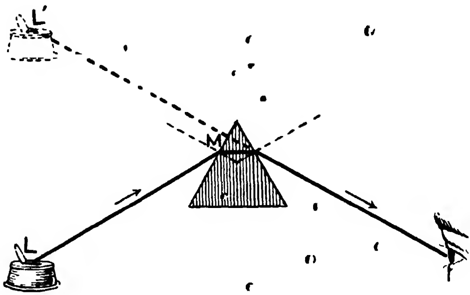
These two facts explain why light in traversing the glass panes of windows, or any other medium with parallel faces, is not turned aside out of its course.

Here is another piece of glass, with three faces inclined towards each other at an angle. If you look at the end of it, you will see that it is triangular, or wedge-shaped; we speak of it as a prism.

The first thing no doubt to strike you on looking through the prism is that, all objects seen through it appear to be coloured, as though they were lighted up with bands of different coloured light. But we shall disregard this entirely, because for the present we are concerned only with the direction which the rays of light take, and not with colour.

I want you to look through the prism now at some object—say this inkstand—on the table. You know it is actually below your eye, but you cannot see it by looking down at it through the prism. If however you look straight before you through the glass, you will see the image of it; but it is above the real object, and this proves that the rays of light from the inkstand must in some strange way have been turned out of their course.

Let us now, with the help of a sketch, trace a ray of light from the inkstand through the prism to your eye.



This, the original ray, then falls obliquely on the prism at a certain point, and at that point we will erect a perpendicular—the normal.

You know that when a ray of light passes from a rare into a denser medium—from air into glass—it is bent towards the normal. Therefore it will be an easy matter to draw the refracted ray across the section of the prism till it meets the opposite face.

But at that point it passes out from a dense into a rarer medium, and by the law of refraction is bent away from the normal.

You see from this that the original ray is refracted twice in passing through the prism, and that it is the twice-refracted ray which proceeds to your eye.

In looking through the prism you see, not the inkstand itself, but an image of it, and the image is raised considerably above the object.

Let me point out too that the ray is refracted each time towards the thick part of the prism. You must keep this fact well before you, as it will help you to

understand the nature of a lens, which is to be our next subject for inquiry.

Summary of the Lesson

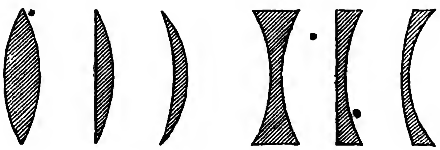
1. Light passes through plate-glass without being turned out of its course.
2. The vertical rays pass directly through the glass, and the oblique rays emerge from it in a direction parallel to their original direction.
3. Light in passing through a prism is refracted twice.
4. Refraction always takes place towards the thick part of the prism.

Lesson XXV

Lenses

We have traced rays of light through plate-glass and prisms, and our next step is to learn how they are affected in passing through lenses. A lens, you know, although made of glass, is not a flat sheet with parallel faces, nor are its sides inclined at an angle like those of a prism.

There are several lenses on the table; take them in your hand and examine them for yourself, and you

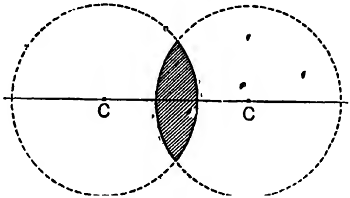


will find that they have curved surfaces. Three of them are thicker at the centre than at the edge, the other three are thin in the centre, and thicker towards

the edge. Those which are thick in the middle are called convex lenses; those which are thin in the middle are concave lenses.

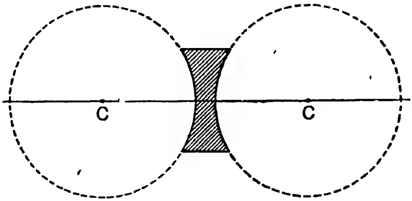
All these different shaped lenses have their uses, but for our present purpose it will be quite sufficient to examine two of them.

Let us begin with the one whose opposite faces are both bulged out, so to speak. This is known as a



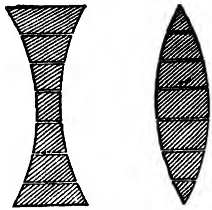
double convex lens, and each face is in reality part of a sphere. The centres of the two spheres are known as the centres of curvature, and the line which joins the two centres is called the principal axis.

The other, a double concave lens, is also formed by two spheres. That is to say, each of its curved surfaces is part of a hollow sphere, and it has its centres of curvature and principal axis just like the convex lens.

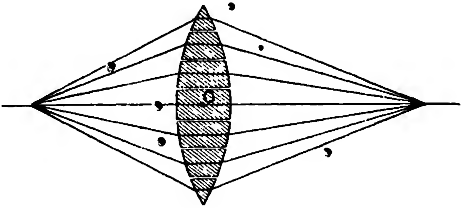


faces is part of a hollow sphere, and it has its centres of curvature and principal axis just like the convex lens.

Now imagine each lens to be cut through, or divided into a number of separate parts. Every individual part might then be regarded as a prism, with its opposite faces inclined to each other at an angle; and you already know that light in passing through a prism is refracted towards the thickest part of the glass.



If then we trace the course of a number of rays through each lens, we shall find that in the convex lens, which is thickest in the middle and thin towards the circumference, the rays after refraction always converge to a point; but in the concave lens, which is thinner in the centre

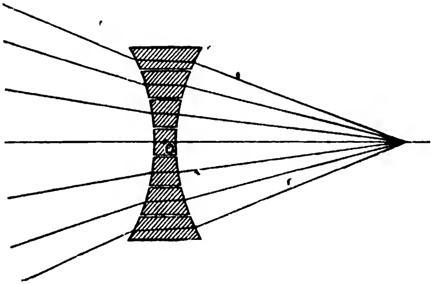


than at the edge, the refracted rays always diverge, or spread out.

This explains why a convex is also called a converging lens, and a concave a diverging lens.

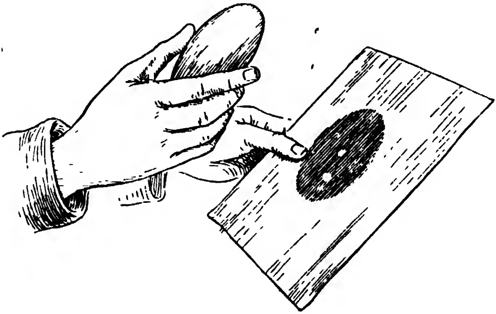
You observe, by the by, that in each lens the principal axis passes through a point in the very centre equidistant from both faces. That point is called the optical centre, and it is important to remember that every ray of light which passes through

the optical centre emerges from the lens without being turned out of its course, because at the point where it strikes the lens the two opposite faces are



practically parallel to each other, like the opposite faces of plate-glass.

I have often seen boys amuse themselves with one of these double convex lenses on a bright sunny



day. They hold the lens in one hand, so that the sun may shine directly upon it, and with the other hand they hold a sheet of white paper behind it to form a screen. Then by moving the lens and the

screen carefully, they find a position in which a very bright circular spot appears on the paper.

But you yourselves are quite familiar with all this, and you know that if the lens and the screen are held steadily in one position, the bright spot soon begins to smoke, and at last the paper takes fire and burns. That is why boys always speak of the lens as a burning glass.

I need scarcely point out that the bright luminous spot on the paper is the focus, to which all the rays of light from the sun are concentrated after passing through the lens. We shall have more to say about this focus in the next lesson.

It will be sufficient for the present to observe that, when a lens is used in this way, heat as well as light is concentrated on that spot, and any inflammable substance may be set on fire if it be placed in the focus. Indeed, if a large lens is used, it is even possible to melt metal.

Summary of the Lesson

1. Convex lenses are thickest at the centre; concave lenses are thickest at the edge.

2. Each part of a lens may be regarded as part of a prism, whose opposite faces are inclined to each other at an angle.

3. Rays of light in passing through a lens are refracted towards the thickest part of the glass.

4. Convex lenses are known as converging lenses; concave as diverging lenses.

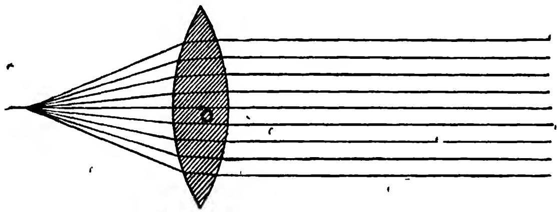
5. Rays which pass through the optical centre are not diverted out of their course.

Lesson XXVI

More about Lenses

Let us return to our burning glass, and the bright luminous spot which it throws on the paper. That spot, you remember, is the focus to which all the rays of sunlight are concentrated after passing through the lens.

You remember, too, that every pencil of light from the sun consists of parallel rays; and therefore



it is clear that when the lens faces the sun, the rays of light which fall upon it must all be parallel to its principal axis.

One of these rays, and only one—that which coincides with the principal axis—passes directly through the lens without refraction, because at the point where this ray strikes the lens the two opposite faces are parallel.

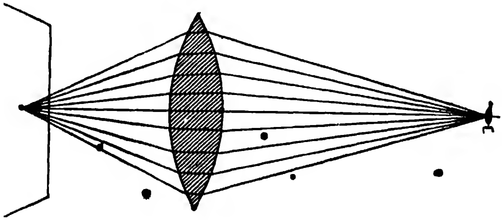
In every other part of the lens the opposite faces are more or less inclined to each other, like the faces of a prism. Hence the rays of sunlight fall on them obliquely, and are refracted, or bent towards the thickest part of the glass—and the nearer they are to

the edge of the lens, the more they are refracted, so that they all meet at last in the one luminous spot.

This spot, to which all the parallel rays of a pencil of sunlight are concentrated, is known as the principal focus of the lens, and the distance between it and the lens is called the focal length.

But all light does not proceed in parallel rays.

I will pull down the blinds, and stand a small lighted candle on the table, with the same convex lens in front of it at a distance of two or three feet. The light from the candle falls in a divergent pencil on the lens, and if I hold a paper screen on the

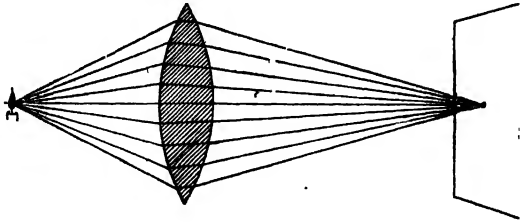


opposite side of it, and move it gradually nearer, I shall at last find a position in which a bright luminous spot will appear on it.

That spot is the focus for all the rays which fall on the lens from the candle flame. They strike the lens as a diverging pencil, are refracted as they pass through it, and meet in this one spot—their focus.

You observe that if we move the lens, so as to vary the distance between it and the candle, the bright spot disappears from the screen. The screen itself must be moved into new positions, as the distance between the candle and the lens is altered. As the candle approaches the lens, the focus recedes

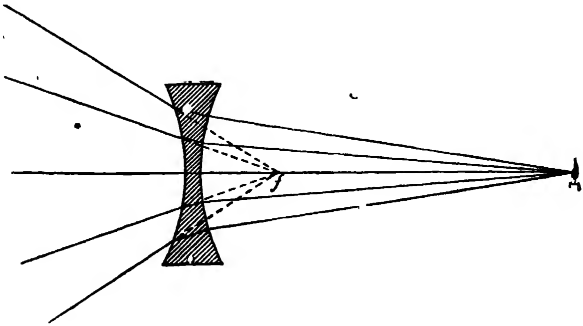
from it; but as the candle is moved away, the focus approaches nearer.



Unlike the principal focus, this one is not at a fixed distance from the lens. Its position depends upon that of the luminous object itself.

The candle and screen can exchange places too, so that this is said to be a conjugate focus.

Now let us look at this other—the double concave lens. It is easy to see that, as refraction always



takes place towards the thickest part of a lens, the rays of light which fall on this one must diverge, or spread outwards.

Hence it is clear that there can be no focus for

these refracted rays on the opposite side of the lens because they spread farther and farther apart.

You will see from this sketch, however, that if those refracted rays were produced backwards, they would all meet on the principal axis.

The point where they meet is the focus of the concave lens; but it is only a virtual focus, for no light passes through it, and no bright spot would appear on the screen if it were held in this position.

Summary of the Lesson

1. The distance between the lens and its principal focus is called the focal length.
2. Every divergent pencil has its own focus.
3. As the object approaches a lens, the focus recedes from it, and *vice versa*.
4. The distance of a conjugate focus from the lens depends upon the distance of the object from it.
5. A concave lens has only a virtual focus.

Lesson XXVII

Images formed by Lenses [1]

It will be interesting and instructive now to follow on with a few simple experiments, to show how images are formed by different lenses.

Let us then pull down the window blinds, to partially darken the room, and commence operations at once with the double convex lens.

I will place a lighted candle at one end of the table, and stand the lens facing it, and at some

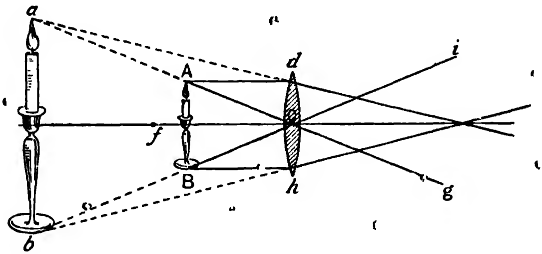
[1] The formation of these images is dealt with more fully in the *Teachers' Manual*.

Parallel rays, of course, can never meet to form a focus, and hence they can never produce an image.

Now for the last step in connection with the convex lens.

I will move the candle still closer to the lens, so that it stands between the lens and its principal focus, and you observe that it is impossible to catch an image of it, wherever the screen is placed.

But if you look through the lens at the candle itself, you will see, not the actual candle, but an image of it very much larger than the one on the



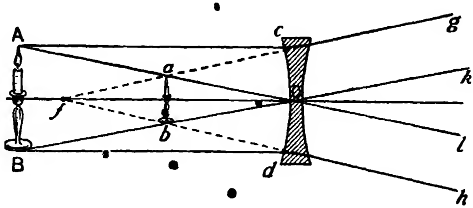
table, and you will find that it is erect, not inverted like those which appear on the screen.

This erect, magnified image, which you see when you look through the lens at the candle, is not really there; it is an illusion—a virtual image—for it is quite plain that the rays of light, which fall on the lens from the candle itself, cannot pass through this image which is behind it.

We learn from this then that, when an object is placed between a convex lens and its principal focus, the image it forms is virtual, erect, and magnified.

So much then for the convex lens. Let us now turn our attention to the other—the concave lens.

This one, you know, is thin in the middle, and thicker towards the edge, and the effect is to cause the rays of light which pass through it to diverge after refraction. Hence it is quite clear that such a lens cannot form a real image on a screen, for its refracted rays cannot be brought to a focus.



Look through this lens at the candle now, as you did through the other one, and you will see an upright image of it, but instead of being larger it is smaller than the object itself. This image, like the last, has no real existence; it is only an illusion—a virtual image,—for the rays of light, which fall on the lens from the candle, cannot possibly pass through the image, which appears between the candle and the lens itself.

Summary of the Lesson

1. When an object is more than twice the focal length from a lens, the image is real, inverted, and smaller.

2. As the object approaches nearer to the lens, the image increases rapidly in size, and is at a greater distance off; but it is still inverted and real.

3. When the object stands in the principal focus there is no image.

4. When the object is between the lens and its principal focus, the image is erect and larger, but it is only a virtual image.

5. Images formed by concave lenses are virtual, erect, and smaller than the object.

Lesson XXVIII

Nature's Optical Instrument—The Eye

We have been learning a great many interesting and instructive things about light, as one of the Natural Forces, but every step we have taken must have made it more and more clear that all those wonderful provisions of Nature would have been worse than useless, if she had not at the same time endowed living creatures with suitable machinery, in the form of eyes, for appreciating them.

I propose to talk to you now about the eye, which is, after all, the most wonderful optical instrument in the world—and one of Nature's masterpieces.

I have provided myself with a fresh bullock's eye from the butcher; and after we have examined this one, perhaps you will be able to get another and examine it for yourself.

You notice that the greater part of the ball is covered with a thick opaque coat; but this in front gives place to a clear, transparent, horny, circular plate, which is known as the cornea.

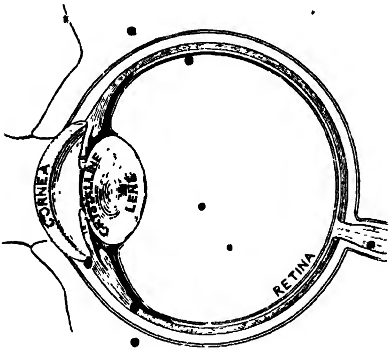
Then, behind this window of the eye is a circular curtain, with a round hole in its centre. The curtain itself is called the iris, and it gives the colour to the eye. The round hole in it is called the pupil: it looks like a round black spot.

I will now cut the eyeball in two with these sharp

scissors, and you see that the operation requires care, as the outer coat is thick, tough, and leathery.

As the cutting goes on you observe that the ball is hollow, and that a clear jelly-like liquid flows out from it; but, ignoring this for the present, I must call your special attention to the small, rounded, lozenge-shaped body, which divides the hollow ball into two chambers—a front and a back one.

This is known as the crystalline lens, and is made of clear transparent material, not unlike a tough kind



of gelatine. It is a double convex lens, like the glass lenses we have examined, and is capable of refracting light which passes through it.

The small chamber between it and the cornea in front is filled with a clear liquid—the aqueous humour; and the larger chamber behind it contains the jelly-like liquid—the vitreous humour, which we saw oozing out when the eyeball was first cut. You observe that this liquid is something like the clear, unboiled white-of-egg in appearance.

The cornea, as I have already pointed out, is the

window of the eye, through which all light must enter; but the circular curtain behind it contracts and expands, to enlarge or diminish the size of the pupil, so as to regulate the amount of light to be admitted.

The light thus admitted is refracted by the transparent humours and the convex crystalline lens, and forms images on the back wall of the eyeball, just as our lenses have from time to time formed images on the paper screen.

This brings me to notice the hinder half of the ball, and especially the delicate, opal-white membrane, which lines the whole of its hollow surface. This is known as the retina; it is thickly spread with the nerves of sight, and they convey to the brain an impression of the image formed there. It is in this way that the sensation of vision is brought about.

But we ought to have a word or two more about that wonderful crystalline lens.

You of course remember that, in an ordinary convex lens rays from distant objects converge to the principal focus, while those from nearer objects find their focus at different points according to their distance from the lens. Put in other words, this means that the distance of the image from the lens in every case depends upon the distance of the object from it.

The back wall of the eyeball, with its network of nerves is, as I have just pointed out, the screen on which all images must be formed, or there can be no sense of sight; and I need scarcely say that the distance between it and the crystalline lens is a fixed one, and cannot be varied to suit objects at different distances.

Let us see how nature provides for this.

You must have observed, during our investigation of different lenses, that the flatter the surface of the lens the greater its focal length; and the greater its convexity the shorter the focal length. A flattened lens, that is to say, produces its images at a greater distance than one which is more convex.

Now for the wonderful adaptation of this wonderful lens. Instead of being rigid like glass, it is very elastic, for it is made of tough gelatinous material.

It can readily alter its convexity to suit the distances of all objects, and in this way sharp, clearly defined images of both near and far objects appear on the retina—the screen, that is, on the back wall of the eyeball.

Summary of the Lesson

1. The cornea is the window of the eye; the crystalline lens does the work of refracting the light which is admitted.
2. The retina is the screen on which images are formed.
3. The nerves of sight carry the impression to the brain.
4. The crystalline lens is able to alter its convexity, to adapt itself to objects at varying distances.

Lesson XXIX

Short Sight and Long Sight

When, in our last talk, I described the eye as the most wonderful optical instrument in the world, of course I meant a strong healthy eye; but unfortunately all eyes are not strong and healthy.

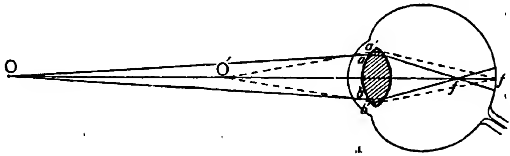
In some the cornea and crystalline lens are too convex; in others they are not convex enough, and either of these defects interferes with perfect vision.

As they are very common defects too, a few words of explanation will be useful.

Let us commence with the first of these abnormal states, which is commonly known as short sight.

If you follow this drawing, which shows you the eyeball in section, with its lens and cornea more convex than they should be, it will help you to understand what is meant by the term, short sight.

Let O be any object at a distance, and from it I will draw rays O*a* and O*b* to meet the crystalline lens in *a* and *b*. All such rays, of course, are refracted as they pass through the lens; but owing to the too rounded form of the lens in this particular case, these



rays are brought to a focus too soon, so that the image, instead of falling on the retina, falls in front of it, and is blurred and indistinct.

Persons with this defect are said to be short-sighted; they have very indistinct vision for objects at a distance.

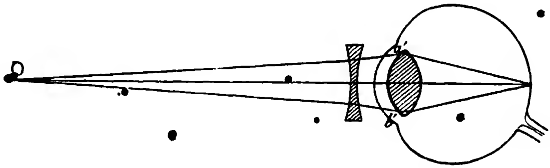
But imagine now the same object nearer the eye at O′. The rays from near objects are more divergent, you know, than those from distant objects, and the rays O′*a*′ and O′*b*′ which proceed from the object in this position will, after passing through the lens, come to a focus on or near the retina, and not in front of it, because, as the object approaches the lens, the image always recedes from it.

In this case a clear distinct image is formed on the retina, and you will now understand why it is that short-sighted people can see near objects clearly enough, although they cannot distinguish distant ones.

Concave spectacles are worn as a remedy for short sight, and you will at once see the effect of such spectacles if you follow this drawing.

The rays which strike this concave glass from the distant object O, are made to diverge, so that they fall on the crystalline lens itself, as if they had come from O′ and not from O.

In this way a natural focus is obtained, and the image is formed on the retina, as if the object itself were actually at O′ and not at O.



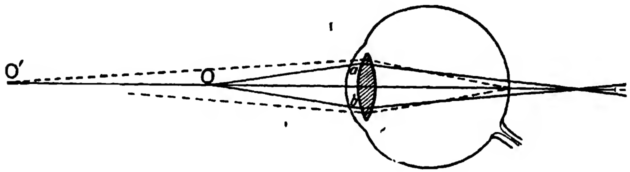
Now let us turn our attention to the other common defect, which we call long-sight. The cause of this, as I have already pointed out, is that the cornea and the crystalline lens are not convex enough. In other words, both are too flat.

This flattening usually comes with old age, and it accounts for the fact that elderly people cannot, as a rule, read the small print of a book, or see objects near them as distinctly as distant ones.

This drawing again will help you to understand the true meaning of the term, long-sight.

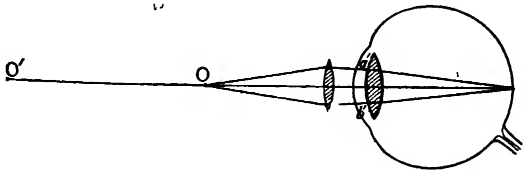
Here we have a section of the eyeball, with its cornea and crystalline lens both too flat.

Let O be any object at a short distance from the eye, and Oa and Ob rays from it falling on the crystalline lens. This flattened lens produces its images at a greater distance than a rounded one would, and the result is that the rays after refraction cannot find a



focus anywhere within the eyeball. Hence no image at all, or a very blurred and indistinct one, is formed on the retina; and people with this defect have very indistinct vision for near objects.

I may remind you once more of the general rule that, as the object recedes from a lens, the image approaches nearer; and then you will understand why it is that rays from distant objects, falling upon this flattened lens, find their focus within the eyeball,



and form clear distinct images of those distant objects on the retina.

People with long sight can see distant objects quite clearly, but cannot see things close to them.

To enable people with this defect to see near objects as clearly as distant ones, convex spectacles are used;

and this drawing will show you the effect of such spectacles.

The rays from the near object O are made to converge as they pass through the convex glass of the spectacles, and after being refracted in this way, they meet the crystalline lens as if they came from the distant object O′, and not from the near object O, and hence a clear image on the retina is the result.

Summary of the Lesson

1. In short-sighted eyes the cornea and crystalline lens are too rounded.
2. The remedy for this defect is provided by concave spectacles.
3. In long-sighted eyes the cornea and crystalline lens are too flat.
4. Convex spectacles provide the remedy for this defect.

Lesson XXX

Some of Man's Optical Instruments

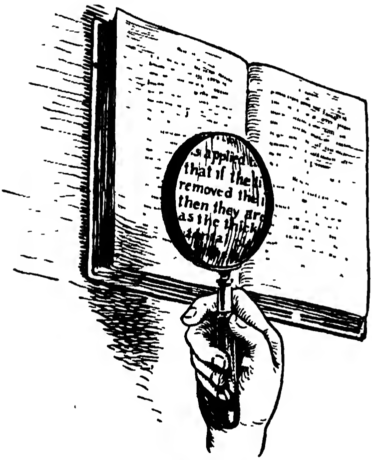
Our recent lessons on the eye, as Nature's masterpiece in the way of optical instruments, lead us now by easy steps to consider some of those other instruments and contrivances which man has invented and made, to assist the eye where it is necessary.

We have already seen that, from various causes, the eyes, instead of being strong and healthy as Nature made them, are often defective, some being unable to distinguish things at a distance, others having the same difficulty with objects close to them, and you know that these defects are remedied by the use of

spectacles, specially suited for short sight or long sight, as the case may be.

But there are some things far too small, and others far too distant, for the healthiest and strongest eyes to see, and our next step will be to learn what man, by his own clever invention, has done to assist Nature in such cases.

Here is a very simple instrument, commonly known



as a hand lens. It is merely a convex or converging lens, set in a frame with a handle for holding it.

If you take it in your hand, and look through it closely at different objects, you find that those things appear magnified or enlarged, and you yourselves probably know it as a magnifying glass. But I will now show you that its power for magnifying depends entirely on its distance from the object.

Let us begin by holding it close up to the page of

this book, and you will see by looking through it that the letters appear much larger than they really are.

You remember, of course, that when a lens is held close up to an object, whatever it may be, that object is between the lens and its principal focus.

You no doubt also remember that, if a convex lens is held close up to an object in this way, it always gives an enlarged, upright, and virtual image.

Our lens then, in this position, is a magnifying

glass, for it shows upright enlarged images, not only of the letters in the book, but of all objects when we look at them closely.

Now move the lens slowly back from the book, and observe what happens. When it reaches a certain distance from the page the letters disappear altogether, and the lens shows nothing but a blank white disc.

I need scarcely remind you that we have seen this same sudden disappearance before, and you will doubt-

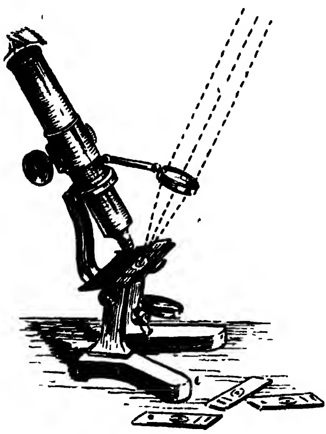
less recognise that the printed page is now in the principal focus of the lens, where no image can be formed. Hence it is clear that in this position the lens loses its magnifying power.

Now lastly observe what happens, as the lens is moved still farther back from the book. In this new position the letters reappear, but they are now inverted as well as magnified.

This again is not new to us, for we know that the book is now just beyond the principal focus, and the lens at this distance always gives a real, inverted and enlarged image. For practical purposes, you see, the lens in this position again ceases to be useful as a magnifying glass, because the image is inverted.

Hence it is clear that the lens is employed as a magnifying glass in one position only, and that is when the object is between it and the principal focus.

Convex lenses are used as magnifying glasses by watchmakers and engravers, to enable them to see clearly the intricate and delicate work on which they are engaged; and they are also used by aged people as reading glasses, to assist them in deciphering small print.



A lens employed in this way is a simple microscope. It serves the purpose for which it is used, but it cannot magnify objects to any very great extent.

Compound microscopes are very elaborate instruments, and some of them are capable of magnifying an object to many hundred times the original size.

They are all constructed on this same principle, but instead of a single lens there are two—one called the eye-piece, the other the object glass.

The object glass gives an enlarged image of the object, and the image itself is further magnified by the eye-piece; and to assist these lenses a concave mirror is fixed in such a position as to throw all possible light on the object which is being examined.

Summary of the Lesson

1. A convex lens becomes a magnifying glass when it is held close up to an object.
2. In this position it forms a virtual, erect, and enlarged image of the object.
3. When it is held so that the object is in the principal focus no image is formed.
4. When it is held still farther away from the object the image formed is real, inverted, and enlarged.
5. A compound microscope is fitted with two lenses—an object glass and an eye-piece.

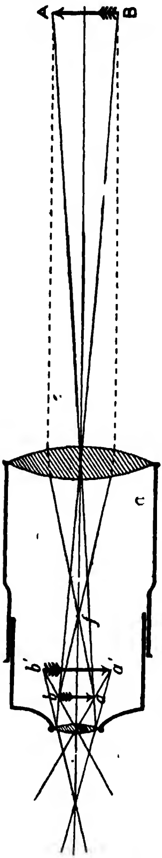
Lesson XXXI

Another Optical Instrument—The Telescope

Our observations have proved clearly enough that the eye, although such a wonderful and perfect instrument, is after all decidedly limited in its powers.

It cannot see very small things, however close they may be; and it is equally unable to see things of any kind, if they are at a great distance.

The microscope is man's invention to show distinctly objects that are far too small to be seen by the unaided eye, and it accomplishes this, as you now know, by producing magnified images of those very small objects.



Let us next turn our attention to that other artificial contrivance—the telescope—which enables an observer to view things at a very great distance.

Ordinary telescopes are used for viewing distant objects on land and sea; and these are called terrestrial telescopes. Others are employed for observing the heavenly bodies, and are hence known as astronomical telescopes.

For reasons which you will understand better as we go on, the astronomical telescope is less complicated in structure than the terrestrial, so it will perhaps be best to confine ourselves to that.

The essential parts of this telescope are two double convex lenses. One is of large diameter, and is called the object glass, the other is smaller, but more convergent, and is known as the eye-piece.

Each of these lenses is fitted into one end of a tube, and the eye-tube being smaller than the other slides easily into it, so that the eye-piece at one end of the instrument and the object glass at the other can be brought nearer together, or drawn farther apart at will.

If you follow this drawing it will help you to understand how the telescope makes distant objects visible.

In it we have, as you can see, the two tubes, one larger than the other, and at the end of the larger tube I have drawn the object glass in section, with a line ruled through it at right angles to represent its principal axis.

If then we take AB to represent some distant object, you know that all rays from it must fall on the object glass in a direction parallel to the principal axis, and that these rays after refraction by the lens converge to the principal focus.

We will represent these parallel rays by dotted lines till they meet the lens, and it will then be easy to show them, as they converge and cross at the principal focus. After passing through the focus they proceed to *a*, *b*, where they form a real, inverted image of the object AB.

Now let us turn our attention to the smaller lens, or eye-piece, which I will draw in section at the opposite end of the eye-tube. The two lenses are so placed that the principal axis of one is in a line with that of the other.

You observe that the image *a*, *b* is formed close up to this smaller lens; in fact it is between that lens and its principal focus.

But this very image now becomes the object of the eye-piece, and you of course remember that in this position rays from it, after suffering refraction, produce a virtual, upright and enlarged image *a′ b′*.

This is the image which the observer sees on looking through the eye-piece of the telescope, and

you will readily discover that, although it is upright with respect to the first image, it is inverted with regard to AB.

This is of no consequence when viewing the heavenly bodies, but of course it would not do for other purposes, because everything would appear upside down.

You will understand now why another form of the instrument—the terrestrial telescope—is used for that purpose; but it is too complicated for us to consider here.

Summary of the Lesson

1. Telescopes are employed to obtain views of very distant objects.
2. The object glass forms a real inverted image of the object.
3. The eye-piece gives a virtual, upright, and enlarged image of the image formed by the object glass.

Lesson XXXII

Some other useful Lenses

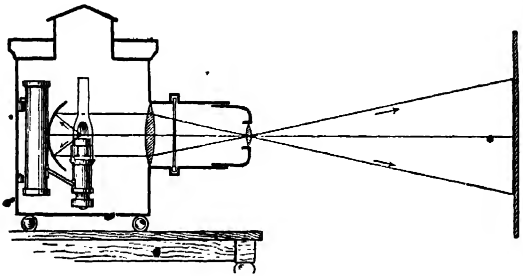
Spectacles, microscopes, and telescopes have been invented, as you know, for the sole purpose of assisting the eye, in one way or another, to gain a more perfect vision than it could possibly get without such assistance. But besides these invaluable aids to vision, we have many clever optical contrivances in common use, and a brief notice of some of them will form a fitting close to these lessons on light.

Suppose we commence with the well-known magic-

lantern; you will no doubt be interested to learn how it produces its pictures on the sheet.

The first essential of this contrivance then is a very bright light, either from a lamp or some other source; and this light is placed in the principal focus of a highly polished concave mirror, fixed in the back wall of the lantern itself.

If you carry your minds back for a moment to our experiments with the concave mirror, you will remember that all the light which falls on such a



mirror from its principal focus is reflected in parallel rays.

Now notice in the next place the large convex lens, which is fixed in the front wall of the lantern, exactly opposite the mirror. This lens is called the condenser, and all the parallel rays reflected from the mirror must fall on it. But a convex lens, as you know, converges all parallel rays of light towards its principal focus. The result of this two-fold arrangement is that the light from the lamp, after being reflected in parallel rays by the mirror, is refracted by the condenser, and made to converge towards its principal focus on the other side.

But in the path of these refracted rays stands the glass slide, containing the picture which is to be thrown on the screen; and it is clear that those rays must pass through this transparent slide.

Now in the next place observe that in front of the slide is another convex lens, not fixed like the condenser, but movable. It can be moved to varying distances from the slide, but its nearest approach to it is rather more than the focal length.

If you remember this fact, and our earlier experiments with the convex lens, you will readily understand the rest.

The rays of light, after passing through the slide, fall on this front lens, and are again refracted; and these refracted rays produce on the screen a real, inverted, and greatly magnified image or picture.

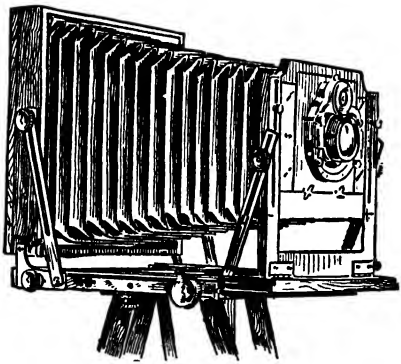
You know, perhaps, that in working the magic-lantern, we always place the slides upside down. The reason of course is now clear, for as the images produced by these lenses are always inverted, it is necessary to stand the object itself upside down, if we wish to get an upright picture on the screen.

Now, in the next place, let us turn our attention to the photographic camera; and as an introduction to it, I want you to carry your mind back to our pinhole experiment, which gave us an inverted image of the candle.

You remember that for this experiment a small hole is bored in the bottom of a round tin canister, the inside of which is blackened with lamp-black. A cardboard tube, made to fit it exactly, is then closed at one end with a cap of tracing paper, and the closed end is thrust into the open end of the canister.

When we look into this cardboard tube, we see on the tracing paper screen an inverted image of the candle, which stands in front of the pin-hole at the opposite end of the canister.

Here is the whole thing, just as we had it in the earlier lesson; and you observe that, as the tube is pushed farther in, the image on the screen becomes smaller, but at the same time sharper and more clearly defined; while as it is drawn out, the image



increases in size, but becomes blurred and less distinct.

This contrivance is known as the pin-hole camera, and if we substitute a convex lens for the pin-hole, we shall have in it all the essentials of the camera, which is actually used in photography.

The photographic camera is practically a rectangular box consisting of two parts, one of which is fixed, the other capable of being drawn out, or pushed in like a drawer.

In front of the box there is, in place of the pin-

hole, a brass tube, which forms the setting for a condensing lens—the object glass, and this too, as well as the box itself, can be moved backwards and forwards.

Facing this lens on the opposite side of the box is a screen of ground-glass, which can be removed at will; and when the camera is placed before an object, an inverted image appears on this screen.

The photographer's first aim is to get a clear, sharply defined picture, and he accomplishes this by carefully adjusting the camera and its lens, till he gets the correct focus. That done, he removes the ground-glass screen, and substitutes for it a glass slide, which has been sensitised, or made capable of receiving and holding the image thrown on it by the lens. This part of photography, however, is dependent upon chemistry, and has nothing directly to do with our present inquiries into light.

Summary of the Lesson

1. A magic lantern is the combined result of a concave mirror and convex lenses.

2. The concave mirror reflects the light in parallel rays on the condensing lens in front of it.

3. The lens refracts the parallel rays, so as to make them converge towards its principal focus.

4. The picture thrown on the screen is a real, inverted, and greatly enlarged image of the painted glass slide.

5. The photographic camera consists of a box with a condensing lens in front and a ground-glass screen at the back.

6. The picture, an inverted one, is first thrown on this screen by the lens.

7. It is then made sharp and clearly defined by adjusting the camera and its lens.

8. A sensitised glass slide, capable of receiving and holding the image, is then substituted for the ground-glass screen.

Lesson XXXIII

MAGNETS

I have here two pieces of iron-ore for you to examine. If you take them in your hands and compare them, you will find them so much alike, that it is impossible to tell one from the other, for both are hard, heavy, stony substances, and both are exactly the same colour —a rusty black.

As you cannot discover any difference in them, we will place them side by side in this saucer of iron filings, and you shall tell me what you observe when you take them out again.

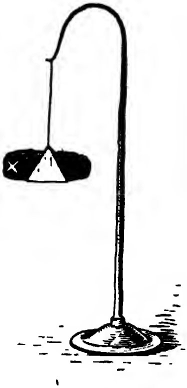
Yes, I thought you would be surprised. You have indeed found a striking difference between these two specimens of iron-ore, and you could not have discovered it in any other way. One piece has thick tufts of the filings clinging to it, but there are no filings at all on the other.

The fact is, the one kind of ore has the power of attracting small pieces of iron, but there is no such property in the other specimen.

This special kind of iron-ore has been known from very ancient times. It was abundant thousands of years ago in Magnesia, a province of Asia Minor, and, like many other things, took its name from the place where it was found, so that it came to be called a magnet, and magnetic iron-ore.

All ores, of course, are natural products, and that explains why we sometimes speak of this as a natural magnet.

But it has another name, lodestone, and that also requires some explanation. I will place it, just as it is, in this paper stirrup, and set it swinging. You observe that, after swinging for some time, it finally comes to rest with one end pointing in a certain direction.



We will chalk that end, and set it swinging again, and you observe that when it comes to rest this time, the chalked end points in the same direction as before; and, more strange still, it will continue to point in that one direction as often as we test it.

Because this magnetic iron-ore always leads or points in one direction when it is freely suspended, it has taken the name of lodestone, which really means leading-stone.

Here is an ordinary steel knitting-needle. Observe that it has no power to attract the iron filings, if I dip it into them; and if I set it swinging in the stirrup, it does not come to rest in the same position every time. Of course it is not a magnet.

But watch what happens next, for it is almost like magic. I merely stroke the needle a few times from end to end with the piece of lodestone, and you observe that, when it is thrust into the filings now, they cling to it in a thick tuft. Moreover, if I put it into the stirrup, and set it swinging, you observe that every time it comes to rest, it points in the same direction. The needle is now a magnet.

You do not require me to point out that needles are not natural magnets, like the piece of lodestone,

for they are not dug out of the earth as a natural product. Indeed, this needle was not a magnet when we saw it at first.

It has been made a magnet, and that is why we call it an artificial magnet. The ordinary steel needle was made a magnet by stroking it with the lodestone.

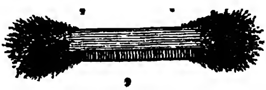
Here is another artificial magnet; it looks like a simple steel bar, but test it for yourself, and you will find that the filings cling to it, and that when it is suspended in the stirrup, it points constantly in one direction.

Observe further that when I draw the end of it a few times along a steel knitting-needle, it changes that needle into a magnet, just as the piece of lodestone changed the other one.

Hence it is clear that the bar of steel is *a magnet, for it has all the properties we have discovered in the natural lodestone.*

Most of the magnets made for use—*artificial magnets*, as we call them—are straight bars of steel like this, and are called bar magnets. But there is another form of magnet, known as the horse-shoe magnet, and it is so named because the bar is bent round in the form of a horse-shoe.

Now suppose we go a step further. I place the bar magnet in the filings, and after seeing that it has been well covered, I take it out again for inspection.



You observe that the filings cling in thick tufts at the two ends, that the tufts are equally thick at each end, and that there are none in the middle.

This, of course, is sufficient to prove that all the

attractive force of the magnet must be at its opposite ends; that the force is equal at both ends; and that there is no attractive force at all in the middle of the bar. It also leads me to explain that the two ends are called the poles of the magnet, while the middle of the bar, where there is no attractive force, is known as the neutral line.

Now let us once more suspend the bar magnet in the stirrup, and set it swinging again.

You observe, of course, that when it comes to rest, the same end, or pole as we now call it, points in the original direction, that is, towards one particular part of the room; and if you think for a moment of your geography lessons, you will find that this particular part is the north end of the room.

It is clear then that one pole of the magnet always points to the north, and hence this is known as the north-seeking pole, because whenever a magnet is left freely suspended, that pole always seeks the north.

But if one pole points to the north, it follows that the other must point to the south, and therefore the opposite pole, for similar reasons, has been named the south-seeking pole.

You must henceforth speak of the two ends of a magnet as the north-seeking and south-seeking poles; and the line that joins the two poles is known as the magnetic axis.

Summary of the Lesson

1. Lodestone, natural magnet, and magnetic iron-ore are three names for the same substance.

2. This special kind of iron-ore has the property of attracting small pieces of iron.

3. It is called lodestone, or leading-stone, because when it is suspended it always settles to rest pointing in one direction.

4. Artificial magnets are made of steel. Lodestone is not made; it is found as a natural product, like any other ore.

5. All the attractive force of a magnet is at its opposite ends, which are called poles.

6. When a suspended magnet comes to rest, one pole points to the north, and is called the north-seeking pole; the other points to the south, and is known as the south-seeking pole.

Lesson XXXIV

Magnets and their Work

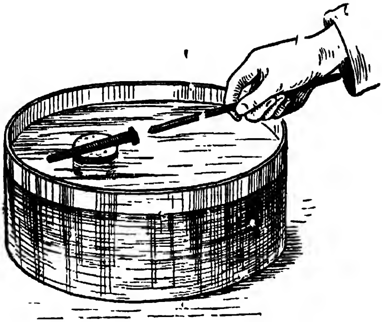
We have seen that magnets, by virtue of a peculiar influence which they possess, are able to attract and hold iron filings. Our next step in dealing with them and their work is, to find out how one magnet acts upon another, and with this object in view we will commence once more with a simple experiment.

Here are some ordinary iron nails. I suspend one of them in the paper stirrup, and place the other on this floating cork. Now observe that, when I bring this knitting-needle near, the result is the same in each case.

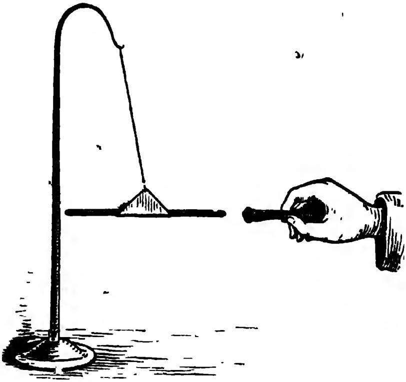
Both nails—the one in the stirrup, and the other on the floating cork—move towards the needle, and you at once infer from this that the needle must be a magnet.

Well, you are quite correct in your inference. This knitting-needle is a magnet; I made it a magnet in readiness for our lesson. It has the power of attracting the iron nail; and the attractive force which it possesses is known as magnetic attraction.

But let us go a step further. Take the knitting-needle magnet in your own hand, and present each end



of it in succession to the two nails. You observe that the result is always the same, for both ends, or poles,



attract the nail with equal force, and the needle may be applied to any part of the nail.

Now, place the knitting-needle magnet in the

stirrup, and take the nail in your hand; and as soon as the needle is quite still, bring the nail near it.

You observe that this time it is the suspended needle which moves towards the nail, for the nail is held in the hand and cannot move.

Of course the needle could not move of itself. It moves because the iron nail attracts it; and hence we see that there is mutual attraction between the magnet and the iron nail. The magnet attracts the nail, and the nail attracts the magnet.

Now, while the needle is still suspended, apply the nail to each end of it in succession, and you observe that the needle every time moves towards the nail, because attraction takes place at either pole.

Let us pass on from this to find out how one magnet acts upon another.

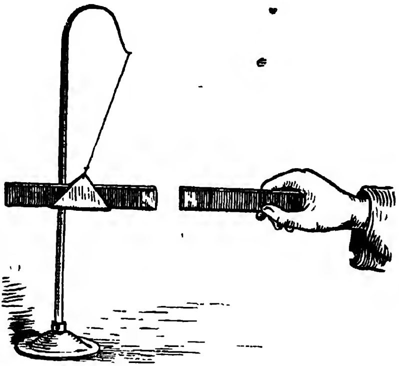
I have here two other knitting-needles, and if you test them in the usual way with the filings and the stirrup, you will find that both possess the well-known properties of a magnet,—they attract the filings, and they also point to the north when freely suspended.

Both the needles then are magnets; they were magnetised, or made into magnets, in readiness for the experiment. That being so, before we go any further, let me remind you that all the force which each one is capable of exerting is at its two ends, and that these ends are called the poles of the magnet.

Having made this clear, we will suspend one of them in the stirrup in the usual way. Then if you take the other in your hand, and present each of its poles in succession to the same pole of the suspended needle, you at once observe that one pole attracts it, the other drives it away.

Then present both poles in succession to the other end of the suspended needle, and exactly the same thing happens. One pole attracts; the other repels.

I will now repeat the experiment, with one of the needle magnets balanced on a cork floating in a bowl of water, and you see that the result is still the same. Each pole of the needle magnet which I hold in my hand attracts one pole of the floating needle, and repels the other.



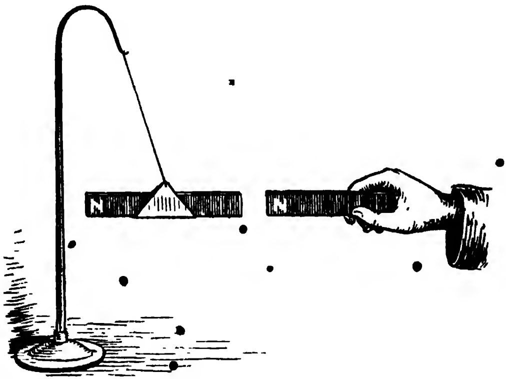
The result is exactly the same if I substitute one of the bar magnets for the suspended needle magnet, and present to each of its ends in succession the two poles of the other. One pole attracts the suspended magnet; the opposite pole, presented to the same end, repels it.

Now let us examine these bar magnets, and see what we can make of all this.

You notice that one end of each magnet is marked, and you know that this is the north-seeking pole, and the opposite end the south-seeking pole.

Take this one in your hand by the south-seeking end, and present the opposite end, that is the north-seeking pole, to the similarly marked end of the suspended magnet, and you observe that the moment this is done the suspended magnet flies off. The one in your hand repels it, or drives it away.

Now in the next place bring the same pole of your magnet to the south-seeking pole of the suspended magnet, and you find that the result is equally



clear, for the suspended magnet is at once attracted towards the other.

Lastly, repeat the experiment with the south-seeking pole of your own magnet, and you observe that it attracts the north-seeking pole of the suspended magnet, and repels the south-seeking pole.

These experiments then make it clear that, the north-seeking pole of one magnet repels the north-seeking pole of another, but attracts its south-seeking pole; while the south-seeking pole of one repels the

south-seeking pole of another, and attracts its north-seeking pole.

This is put in simple language by saying that *like poles repel, unlike poles attract*; and these two statements constitute the first law of magnetism.

Summary of the Lesson

1. A magnet attracts iron and steel at both its poles.
2. A piece of iron attracts a magnet, when presented to either pole.
3. The magnet attracts the iron; the iron attracts the magnet.
4. Repulsion, as well as attraction, takes place between two magnets.
5. Like poles repel; unlike poles attract.

Lesson XXXV

Magnets and Magnetic Substances

In our experiments thus far with the suspended magnet, we have employed the rough-and-ready method of placing it in the paper stirrup, and leaving it free to swing. We will now go a step further.

This little instrument is called the magnetic needle, and it consists, as you see, of two parts—an upright stand with a pointed top, and a long thin strip of steel which rests upon it.

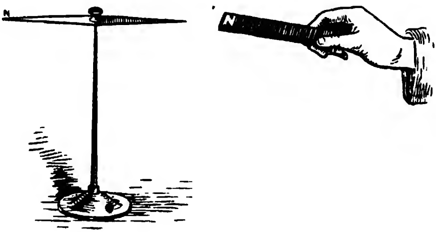
This strip of steel is the most important part of the contrivance—in fact it does all the work, the stand being only a support for it.

It is commonly known as *the needle*, although a glance is sufficient to show that it has no sort of resemblance to an actual needle.

You observe that it is pointed at both ends, and that one of the ends is marked.

It has a small brass cap in the middle, and this cap rests on the point of the upright steel rod. The needle in fact balances itself on this point, and is free to move in a horizontal plane, just as it would be if it were suspended in the stirrup.

Watch it as it swings round, and note that when it comes to rest, its marked end points to the north. That, of course, leads us to infer that it is a magnet, and if we dip it into iron filings, we get a further



proof of this, for you see the filings cling to it as they do to all magnets.

Yes, the needle is a magnet, although it is neither a bar, nor a horse-shoe; it is an artificial magnet in another form.

Since we know then that the needle is an actual magnet, our next step must be to learn how it is used. We will therefore replace it on the pivot, and proceed to test it.

Bring the marked end of the bar magnet near the marked end of the needle, and you observe that the needle at once flies back; the bar magnet repels it.

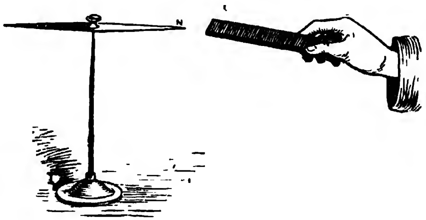
Now present the opposite end of the bar magnet

to the same end of the needle, and you see that this time the needle is attracted to the bar magnet.

We will next repeat both tests at the unmarked end of the needle, and we find that the bar magnet produces the same results at that end. One pole of the bar magnet repels the needle; the other, presented to the same end, attracts it.

Now why does the bar magnet first repel and then attract the needle?

Ah! I am glad to see you have not forgotten. The marked ends of both the needle and the bar



magnet are north-seeking poles; the unmarked ends of both are south-seeking poles.

Like poles repel, and therefore the marked end of the bar magnet repels the marked end of the magnetic needle, and the unmarked end of one repels the unmarked end of the other. On the contrary, *unlike poles attract,* and that explains why the marked end of one attracts the unmarked end of the other.

Now suppose we leave the magnetic needle for the present, while we take our next step.

I have here a saucer filled with small leaden shot, and on the table there are some little piles of copper and brass filings, sawdust, sand, and bran, and I want

you to thrust the bar magnet into the midst of each of them in succession.

You observe that none of these things cling to the magnet, for it comes out every time exactly as it was thrust into them. On the other hand, when the same magnet is dipped into the iron filings and taken out, it brings a thick tuft of the filings out with it.

Take this bar of iron now, and hold it near either end of the magnetic needle, and you observe that the needle moves towards the iron. Repeat the same test with this bar of wood, and these strips of copper, lead, and brass. There is a distinct difference this time, for you see the needle makes no movement.

If I ask you why the iron filings cling to the magnet, you will readily tell me that the magnet attracts them; and if I again ask why the magnetic needle moves towards the iron bar, you will be equally ready in explaining that the iron attracts the magnet, for you know that there is mutual attraction between the two.

These experiments prove that, although mutual attraction exists between a magnet and iron, there is no such attractive force between the same magnet and copper, brass, lead, wood, sand, or bran; and that naturally leads us to compare this magnetic attraction with the attraction of gravitation.

The force of gravitation, you remember, causes every particle of matter of every kind to attract every other particle of matter; but the force which a magnet possesses will only attract certain bodies, and they are therefore known as magnetic substances.

Hence iron, and of course steel which is a form of

iron, are magnetic substances, and the other things on the table are not.

Any substance which can be attracted by a magnet, or can itself attract a magnet is a magnetic substance; and besides iron and steel, certain other metals, such as nickel and cobalt, have this property, but in a lower degree.

Now let us once more bring both ends of the iron bar in succession near each pole of the magnetic needle as before, and you observe that each end of the bar attracts each pole of the needle.

That done, repeat the test with the bar magnet instead of the iron bar, and you find that each pole of the bar magnet repels one pole of the needle, and attracts the other.

You must keep this difference well before you, for it affords the surest test for distinguishing a magnet from a mere magnetic substance.

Any ordinary piece of unmagnetised iron will attract both poles of the magnetic needle; but if the substance we are testing repels the needle at either of its poles, we may be sure that it is not only a magnetic substance, but an actual magnet.

Summary of the Lesson

1. The magnetic needle is a small artificial magnet balanced on the point of an upright steel rod.

2. It is free to move in a horizontal plane.

3. It is made of a long, thin strip of steel, pointed at both ends.

4. Like every other magnet, it has its north-seeking and south-seeking poles.

5. Each pole of a magnet repels a like pole of the needle, and attracts its unlike pole.

6. Magnetic attraction is limited to certain substances.
7. Anything which can attract, or be attracted by, a magnet is a magnetic substance.
8. A magnetic substance attracts both poles of the needle.
9. Repulsion is the only sure test for a magnet.

Lesson XXXVI

The Force of Magnetism

Here are two steel bars, and although there is nothing in their appearance, size, weight, or any other particular to distinguish them, I happen to know that one of them has been magnetised, and the other has not.

Of course both are magnetic substances, but it is only when we apply certain tests that we find, in one of them, a subtle, hidden force, which the other does not possess.

We call this force magnetism; but although we can observe what it does, it is not an easy matter to say what it is. Hence many attempts have been made to solve the question.

Suppose we have a little experiment now, to see what we can learn about it.

Take this piece of thin steel wire in your hand, and prove to me, by the quickest and surest test, whether it is a magnet or not.

Good; I thought you would remember our latest test for a magnet, because although it is infallible, it is so simple. You merely bring one end of the wire near each pole of the magnetic needle in succession, because you know that while a magnetic substance

attracts both poles, a magnet always attracts one pole and repels the other; and repulsion is the surest and best test of a magnet.

In this case you observe that the wire attracts one pole of the needle, and repels the other, and if you test the opposite end in a similar manner, you will get the same result.

This is quite enough, not only to tell you that the wire is a magnet, but also to distinguish between its north-seeking and south-seeking poles. We shall want to recognise these two poles presently, so we will put a mark on the north-seeking pole.

Now follow carefully what I do next. I find by measurement the middle point of the wire, and you remember of course that in this part of a magnet, which is known as the neutral line, there is no attraction.

But I will cut the wire in two at this point, and then if you test both pieces with the help of the magnetic needle, you will no doubt be surprised to find that each half is a perfect magnet, one end of it being a north-seeking pole, the other a south-seeking pole.

Observe also what happens when I cut each of these in two across the middle in the same way as before. We have now four pieces instead of two, and if you test them with the magnetic needle, you will find that each one of these is a perfect magnet, with its north-seeking and south-seeking poles.

Moreover, if I cut these again one by one in the same way, and test the eight separate pieces, I shall find they are eight perfect magnets, and that each one has its north-seeking and south-seeking poles.

These results naturally lead us to infer that, if the cutting and testing were continued till the pieces became too small to handle, every little piece would

prove to be a perfect magnet, one end of which would be a north-seeking pole, and the other a south-seeking pole.

Now for another interesting experiment.

I fill this test-tube loosely with steel filings, and present each end of it to both poles of the magnetic needle in succession.

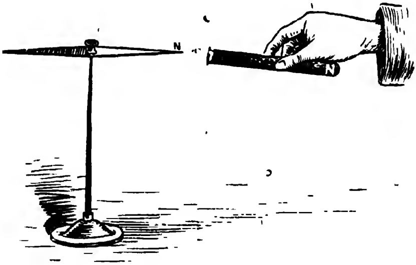
You observe that attraction takes place at each pole of the needle, and that there is no repulsion. Therefore it is clear that the filings in the tube, although made of steel, which is a magnetic substance, cannot satisfy our test for a magnet.

But watch the next step. I stroke the tube slowly about a dozen times from end to end with one of the poles of the bar magnet; and as the stroking goes on, I want you to observe that the little particles of steel move, and arrange themselves in a line with the tube, or in other words, in the direction which the bar magnet takes.

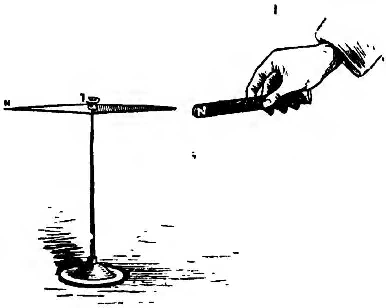
Now that you have seen for yourselves this movement among the filings, I will present first one end of the tube and then the other to each pole of the magnetic needle in succession; and as this is done you observe that, at each of its ends it now attracts one pole of the needle and repels the other.

The fact is, its opposite ends are now north-seeking and south-seeking poles. It acts like any other

magnet, because for all practical purposes it is a magnet. It was magnetised by the bar magnet when the filings arranged themselves in order, end to end.



But we have not done yet. Look; I will shake the tube so as to disturb its contents, and if you examine it now you will see that the filings are no longer arranged end to end, but point in all directions.



Take it as it is now, and test it as before with the magnetic needle, and you will find that attraction takes place at each test; there is no repulsion. Hence it is clear that the tube of filings is no longer a magnet.

Now suppose we compare our tube of filings with the piece of magnetised steel wire. The results of our experiment with the wire, you remember, led us to infer that every little particle of it must be in itself a perfect magnet, and that the north-seeking poles of all of them pointed in one direction, the south-seeking poles in another.

Hence we may naturally assume that, if we could break one of these little pieces into smaller and smaller particles, each would in like manner be a perfect magnet. But even when we have broken matter up into the smallest possible pieces, each of these minute particles is really a mass of molecules, too small to be seen even with the microscope.

These considerations lead us to the further assumption that, every molecule of matter in a magnet is itself a magnet, and has its north-seeking and south-seeking poles.

You remember that when we first saw the filings they filled the tube, but in no particular order, and as a mere magnetic substance they then attracted both poles of the magnetic needle. In that state they resembled the molecules in a piece of unmagnetised steel.

When however they were magnetised, we saw them arrange themselves in order end to end, and then they attracted one pole of the needle and repelled the other, as every magnet does.

Our final conclusions, as the result of these experiments, are that the molecules of a magnetic substance are massed together without any particular arrangement, but that a magnet has the power of causing these molecules to arrange themselves in distinct

regular order, end to end, and when they are so arranged, the magnetic substance becomes an actual magnet.

Then, it is assumed, each molecule becomes in itself a magnet; and in these molecule-magnets all the north-seeking poles point in one direction, and of course all the south-seeking poles directly opposite.

Summary of the Lesson

1. If a magnet is broken into two halves, each half becomes a magnet, and has its north-seeking and south-seeking poles.
2. If both these pieces are broken in halves, and each of those halves is broken again in the same way, every fragment thus made is found to be a perfect magnet.
3. The filings in a glass tube can be magnetised by a bar magnet.
4. When so magnetised they arrange themselves end to end along the tube.
5. The tube of filings in this condition is a magnet, with north-seeking and south-seeking poles.
6. The molecules of a magnetic substance can be forced by a magnet to arrange themselves in regular order, end to end.
7. Each molecule then becomes a magnet.
8. It has all its north-seeking poles pointing in one direction, and all its south-seeking poles pointing exactly opposite.

Lesson XXXVII

Magnetic Induction

These little experiments of ours are more than usually interesting, because they are so simple that you can afterwards repeat them for yourselves. Let us have one or two more now.

I have here two pieces of wire, of exactly the same

length and thickness, one steel, the other soft iron. You will not be surprised that, when I dip them into this heap of iron filings they come out clean, with none of the filings clinging to them, because you know that iron and steel are mere magnetic substances, not magnets, and that magnetic substances have no attractive force.

Now observe what happens when I place the steel wire on the table and bring one of the poles of the bar magnet close up to it. The magnet, you see, not only attracts the steel, but is able to raise it from the table, and support it, hanging by one of its ends.

But suppose you take the other bar magnet in your hand now, and try to do the same with the piece of iron wire. Yes, you see your magnet is able to raise and support the iron wire, just as mine supports the steel.

Now while both are hanging from the magnets, we will dip them into the iron filings once more and watch the result. You observe that when they are withdrawn there is a tuft of filings clinging to the end of each of them; but you notice, too, that the tuft at the end of the iron is bigger than that which clings to the steel. In other words, you find that the soft iron takes up more filings than the steel.

Now follow me, and do with your iron wire exactly what you see me do with my steel wire. I take the wire between the finger and thumb of my left hand,

and gently remove the magnet which I hold in the other. You do the same, and observe that the filings drop at once from both wires; but you see further that, while the iron is left clean, the steel has some of the little particles still clinging to it.

Let us follow this up, and see what is to be learnt from it.

To begin with then, you know that the iron and steel wires were at first mere magnetic substances without any attractive force, and you saw for yourselves that each acquired attractive force, when the magnet came in contact with it.

The magnet, in fact, seemed to exert an influence over both of them, although it had less influence over the steel than over the soft iron, for the steel attracted fewer filings than the iron.

The simple truth is that, while they were under this influence, the iron and steel themselves became magnets; and when that influence was removed, both of them lost their magnetic force—the iron immediately, and the steel more gradually.

In view of this we might call them both temporary magnets, in contrast with bar magnets, horse-shoe magnets, and magnetic needles, which retain the magnetic force originally given them, and are therefore, properly speaking, permanent magnets.

It is clear then that these pieces of iron and steel became temporary magnets, while they were under the influence of the bar magnet; and it is usual to speak of that influence as magnetic induction. The iron and steel are said to have been magnetised by induced magnetism; and for a like reason, the magnet which exerts this influence is called the inducing magnet.

Now let us go a step further. I dip the end of the iron wire into the filings once more, and then very carefully bring one of the poles of the bar magnet near the upper end of it, without allowing the two to touch.

Of course the wire, as a mere magnetic substance, had at first no attractive force for the filings; but you observe that they are now attracted to it, and cling to it in a tuft as before. The wire, although not in contact with the magnet, is under its inducing influence. Hence we see that an inducing magnet is able to induce magnetism in soft iron without coming into actual contact with it.

But you also observe that the tuft is not so big as when the magnet and the iron were in touch, and you see that when the bar magnet is removed the filings at once fall away.

Now watch while I repeat the experiment with the steel wire.

As before, I bring the bar magnet near the top of the wire, without letting the two come into contact, and you observe that this time the filings are not attracted, as they were to the soft iron.

Without actual contact the inducing magnet has little if any influence over steel, although it readily induces magnetism in soft iron under the same conditions.

Summary of the Lesson

1. Soft iron becomes a temporary magnet by induction without contact.

2. Steel, even when in contact with the inducing magnet, is but slightly magnetised.

3. Soft iron loses its magnetism immediately the inducing magnet is taken away.

4. Steel retains for some time what little magnetism it has received from the inducing magnet.

Lesson XXXVIII

Poles of a Temporary Magnet

Before taking our next step, it will be advisable to think over all we have lately learned about induction.

Our last experiment, you remember, proved clearly enough that soft iron becomes a temporary magnet by induction, even without coming into contact with the inducing magnet; but if it is allowed to touch the magnet, the induction is more rapid and more powerful.

Steel, on the other hand, is affected to a very slight extent by induction, even when it is in contact with the inducing magnet. But strangely enough, it retains that slight amount of induced magnetism for some time after the inducing magnet is removed; while iron loses its magnetism immediately the inducing magnet is taken away.

Now let us have another experiment.

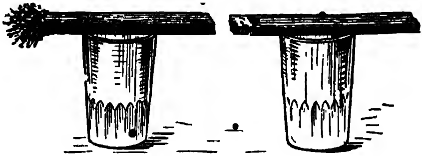
I have here a bar of soft iron, and to show you that it has no magnetic force, I will dip it into these filings. It comes out, you see, as clean as it went in.

That point being quite clear, I will now lay it across this glass tumbler, and on a similar tumbler I will place the bar magnet, so that the two are in a straight line, but not in contact.

Now hold some filings close to the opposite end of the soft iron bar, and observe that they cling to it. Why is this?

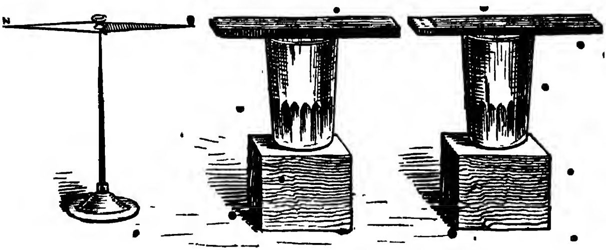
Of course you will at once tell me that the iron bar is now a temporary magnet—that the permanent magnet has induced magnetic force in it, and that this induced magnetism attracts the filings.

See, I can easily prove all this by removing the



bar magnet, for immediately I do so the filings drop, showing that the iron bar has lost its magnetism.

Suppose we replace the bar magnet now, and stand the magnetic needle on the farther side of the iron bar. You observe that, when the needle comes to rest, it points in a line with the inducing magnet and



the soft iron bar. It will not rest in any other position, because the iron bar, as a temporary magnet, is now attracting it.

But perhaps you are not sure that the needle is being attracted by the temporary magnet, so I will prove it to you in a simple way.

Remove the iron bar, and you observe that the

needle immediately veers off in some other direction. The permanent magnet remains there, you see, but the needle, where it stands, is beyond the reach of its magnetic force, and is not affected by it.

Now replace the iron bar once more, and you observe that the needle immediately resumes its old position in a line with it and the permanent magnet.

Hence it is clear that the needle is attracted by the soft iron bar, as a temporary magnet, and not by the bar magnet itself.

Let us, in the next place, examine the bar magnet a little more closely, and we find that the end of it nearest the iron bar is a north-seeking pole; and if after this we pass on to examine the farther pole of the needle—the one which points in the same direction—we shall find that to be also a north-seeking pole.

It is clear, therefore, that its opposite end—the one nearest to the iron bar—must be a south-seeking pole.

I may here remind you that the needle is being acted upon by the soft iron bar, not by the permanent magnet, and that like poles repel, unlike poles attract.

This will be sufficient to prove to you that, as the south-seeking pole of the needle is attracted by one end of the temporary magnet, that end must be a north-seeking pole; and consequently the opposite end must be a south-seeking pole.

It is clear from this that the north-seeking pole of the permanent magnet induces temporary magnetism in the soft iron bar, making its nearest end a south-seeking pole and its opposite end a north-seeking pole.

The north-seeking pole of the temporary magnet,

in its turn, then attracts the south-seeking pole of the needle, and repels its north-seeking pole.

You shall now repeat the experiment for yourselves, but this time we will reverse the position of the permanent magnet by placing its south-seeking pole near the iron bar, and you will then find that all the other poles will be reversed in like manner.

Summary of the Lesson

1. A permanent magnet induces temporary magnetism in a soft iron bar placed in a line with it.

2. The inducing pole repels a like pole in the iron bar, and attracts an unlike pole.

3. A magnetic needle placed on the farther side of this temporary magnet is attracted by it.

4 That pole of the needle, which is thus attracted, is unlike the pole of the temporary magnet which attracts it.

Lesson XXXIX

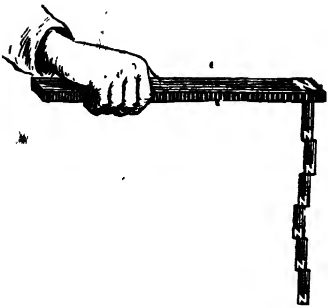
More about Induction

We have still a few more interesting experiments in illustration of the principle of induction. Let us commence to-day with the one which is commonly known as the magnetic chain.

I have here a number of small soft iron rods, and I begin by attaching one of them to a pole of the bar magnet. Either pole, of course, will serve the purpose, but this time it shall be the north-seeking pole.

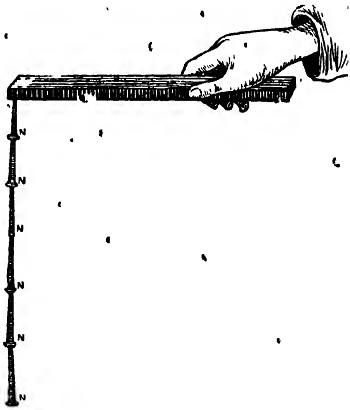
You observe that the iron clings to the magnet, and you know that, in this position, it has itself become a temporary magnet by induction. That being

so, it is clear that the end of it, which is in contact with the permanent magnet, must be a south-seeking pole, and consequently the lower end is a north-seeking pole.



Now I will add a second rod to the lower, or north-seeking pole of this one, and you observe that attraction takes place between the two, for the second rod clings to the first.

But you will at once remind me that this one, like the first, has now become a temporary magnet by induction; and that being the case its upper end must be a south-seeking, and its lower end a north-seeking pole.



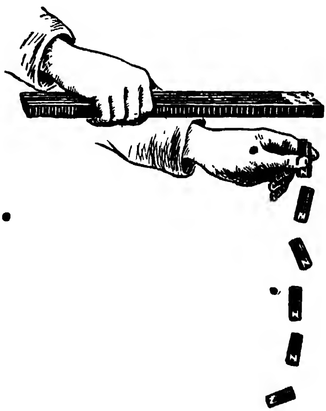
Now follow me while I continue to add rod after rod to the series, until the bar will support no more; and then we will bring the magnetic needle near the lower end of the last piece.

When that is done, you observe, by the deflection of the needle, that this lowest end of the lowest rod is a north-seeking pole like that of the inducing magnet.

We can make a similar arrangement with small iron nails, or with iron rings, and as in each case it consists of separate links held together by magnetic force, it is usually called a magnetic chain.

You understand, of course, that in their present position, all these separate links become temporary magnets, and that each induces magnetic force in the one below it.

Let me prove to you the temporary nature of the magnetism in the whole chain. You see, I have only to take the top rod between the finger and thumb of one hand, and gently remove the magnet which I hold in the other, and the whole chain falls to pieces, because each rod immediately loses its magnetism.



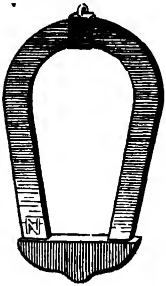
You must have noticed how careful I always am in putting away our magnets after each lesson, and of course you would like to know the reason for all this care.

Here is the horse-shoe magnet just as it was put away, and I want to call your special attention to the piece of iron which clings fast to its two poles.

This is called the keeper, and when a magnet is not in use, it is never left without its keeper.

We will remove the keeper now, and proceed to examine the magnet itself. In the first place, then, let me remind you that this form of magnet is simply

the bar magnet bent round in the shape of a horse-shoe. The marked end is the north-seeking pole; the unmarked end is the south-seeking pole.



Now take the magnet in one hand and the keeper in the other, and bring them close together. You observe that, when the keeper approaches near the poles of the magnet, it is strongly attracted and held fast.

The keeper, you remember, is only a piece of soft iron; and if you think for a moment of some of our recent experiments, you will at once understand that in this position it becomes a temporary magnet by induction.

The north-seeking pole of the permanent magnet induces south-seeking magnetism in the end of the temporary magnet nearest to it, and repels north-seeking magnetism to the opposite end.

At the same time the south-seeking pole of the permanent magnet induces north-seeking magnetism in the end of the temporary magnet nearest to it, and repels south-seeking magnetism to the opposite end.

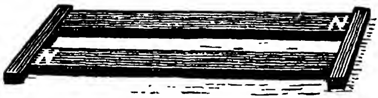
It is clear from this that at each of its poles the permanent magnet holds this soft-iron temporary magnet fast by the attractive force of that pole, and also by the repelling force of the opposite pole.

The piece of soft iron, acting as a temporary magnet, prevents the magnetic force of the permanent magnet from passing away, and hence its name—the keeper. It keeps or preserves the balance between the two poles of the magnet.

Look at these two bar magnets in their wooden

box, just as they were put away when we last used them. You observe that as they lie there, the north-seeking pole of each is at the same end of the box as the south-seeking pole of the other, and in this respect they resemble the horse-shoe magnet, for the opposite poles are side by side.

You see, too, that they are provided with a pair of keepers—one at either end, and of course you will expect that they act in precisely the same way as the keeper of the horse-shoe magnet does.



So they do, for each piece of soft iron becomes a temporary magnet by induction, and in that state keeps or preserves the balance between the opposing poles, and so prevents the magnetic force from being lost.

Summary of the Lesson

1. A magnetic chain consists of several pieces of soft iron, hanging end on end from the pole of a permanent magnet.

2. Each piece of the chain becomes a temporary magnet by induction.

3. The whole of them lose their magnetic force when the inducing magnet is removed.

4. The keeper is a piece of soft iron which is attached to the poles of a horse-shoe magnet, or the opposite poles of a pair of bar magnets when they are not in use.

5. When it is in contact with the magnet, or magnets, it becomes a temporary magnet by induction, and prevents the permanent magnet from losing its force.

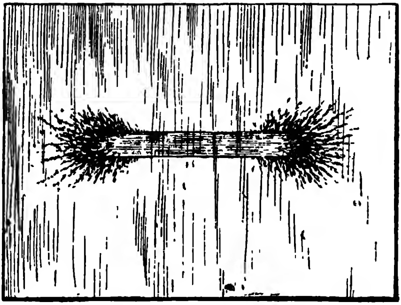
Lesson XL

A Magnet's Sphere of Influence

In our recent experiments we have traced some of the effects of a magnet's influence, both when it touches the magnetic substance, and also when the two are not in actual contact.

Let us in the next place see how far this influence extends.

I place the bar magnet on the table, cover it with a



UNDER A SHEET OF GLASS.

sheet of drawing-paper, and then sprinkle a few iron filings from the dredger on the paper itself, giving it a few taps with the finger to scatter the filings as they fall.

You observe that the filings collect in tufts at the two ends of the magnet, just as they would if it were uncovered.

I will now remove the paper, and substitute for it this sheet of cardboard, and then you shall repeat the experiment yourself. The result, you see, is precisely the same; and so it will be, if we replace the

cardboard with a sheet of glass, or a piece of wooden plank.

The magnet exerts the same influence through all these substances.

Take the sheet of glass now, and hold it out in a horizontal position in front of you. I will lay this piece of soft iron on it, and then if I move one of the poles of the bar magnet to and fro across its under surface, you observe that the iron is attracted by the magnet, and follows its movements in every direction.

Now, while I hold the magnet there, you shall drop some filings on the piece of iron, and as they fall they cling to it, because it is now a temporary magnet by induction.

But notice further, that the moment I remove the bar magnet, the filings fall away from the iron.

These little experiments make it clear that magnetic force acts through all these substances—paper, cardboard, wood, and glass.

We will next substitute this piece of soft sheet-iron for the glass, and you see at once that no action takes place now. Magnetic force does not act through iron, for iron itself is a magnetic substance.

Now suppose we go a step further. I will lay the bar magnet on the table again, and cover it as before with the sheet of cardboard. But this time, instead of sprinkling a few iron filings on the covering sheet, I shall dredge them thickly all over it.

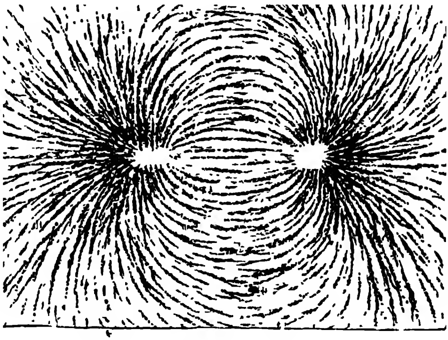
You observe that, as I tap the cardboard with my finger, the filings cluster thickest round the opposite poles of the magnet; and you notice, too, that from those poles they arrange themselves in certain definite curves. These curves, you see, commence at one pole

and end at the other, and are practically parallel to each other.

They are generally known as the lines of force, because they show the direction in which the magnetic force acts.

But if we examine them more closely we find that all these little particles of iron, under the influence of the magnet, have arranged themselves in lines, end to end.

The fact is, each one has become a magnet by



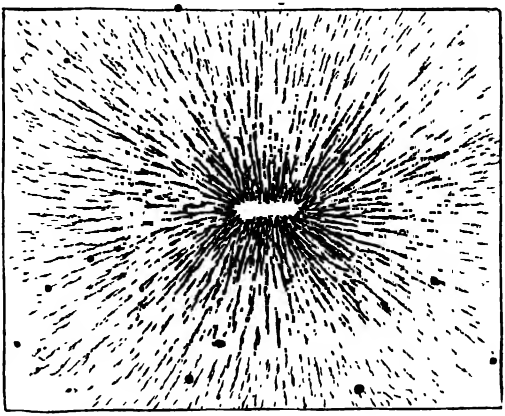
induction, and each one has its north-seeking and south-seeking poles—the north-seeking pole in every case being towards the south-seeking pole of the magnet, and *vice versa,* as a consequence of this induction.

Hence these curves have also been called lines of induction.

I said just now that the curves show the direction in which the magnet exerts its force. So they do, but the magnet does not act merely in the horizontal plane, which is represented by the cardboard.

See, I will stand the other magnet on one of its ends, and rest this sheet of cardboard on it. Then you observe that, if I dredge filings thickly on this, as I did on the other sheet, they radiate in all directions from the pole of the magnet, but do not form curves.

If at the same time you compare the positions of the two magnets, you will see that the first one lies full length on the table, and the lines of force extend in the same horizontal plane; while this one stands



on end, and the lines of force are in a plane at right angles to it.

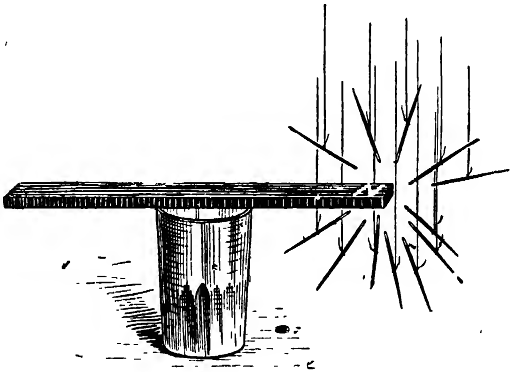
Now for a further experiment. I have here a small sewing needle, and a thread of silk has been attached to its middle point by means of a small drop of hot shellac. We will place the magnet on a tumbler as a support, and you shall observe what happens, when I hang the needle within a few inches of either of its poles.

You see that in every position—above, below, right

or left of the magnet—the needle always points to the pole; and you will have no difficulty in explaining that this is due to the influence which the magnet exercises over it.

Whenever it is placed within a certain distance of the magnet, the needle becomes a magnet by induction, and another needle suspended in a line with it would be affected in the same way.

You remember, of course, that when we dip the



magnet into filings, they not only form in a thick tuft, but they all point outwards from the magnetic pole in every direction.

You have only to imagine every little particle stretched out in its own direction to form one of the magnetic curves, and you will have a very clear idea of the space through which the magnet exerts its force.

I have been at some trouble to explain this because, in scientific language, the space through which

a magnet exercises its force is known as the magnetic field, and this might be deceptive and puzzling to you, for when we speak of a field we usually have in our mind a flat surface. The magnet field is not a flat surface; it comprises the whole of the space surrounding the magnet.

Summary of the Lesson

1. A magnet exerts its attracting and repelling forces through certain substances, such as paper, cardboard, wood, glass.
2. It will not act through sheet-iron, because iron itself is a magnetic substance.
3. When a piece of cardboard is laid on a magnet, and filings are sprinkled on it, magnetic curves are formed.
4. The filings arrange themselves, end to end, in curved lines, beginning at one pole of the magnet and ending at the other.
5. These curves are called lines of force.
6. The magnet exerts its force along these lines, making every particle of the iron filings a temporary magnet by induction.
7. Hence these magnetic curves are also known as lines of induction.
8. The magnetic field is the entire space surrounding the magnet through which its force is felt.

Lesson XLI

Dip and the Dipping Needle

I have some very interesting experiments for our lesson to-day, so to start with, I will place the bar magnet on the table, and stand the magnetic needle on its neutral line.

When this is done, you observe that the needle settles to rest in a line with the magnet below, and

that each pole of the magnet attracts an unlike pole of the needle.

You notice, too, that, no matter how often the needle is set moving, it always returns to the same position.

Now if you compare the two magnets, you will readily see that one is very much bigger than the other, and this fact naturally leads us to infer that the bigger and stronger magnet exercises an influence over the weaker one, and is able to coerce it.

Now for another experiment. I have here a small sewing needle, which I have magnetised in readiness for the lesson, and to its middle point a fine silk thread has been attached in the usual way with hot shellac.

We will suspend our little magnet then, so that the thread itself hangs immediately over the neutral line of the bar magnet.

You notice, of course, that this suspended magnet, unlike the needle magnet, is free to move in any direction; and you observe that when it comes to rest, it assumes a horizontal position in a line with the bar magnet.

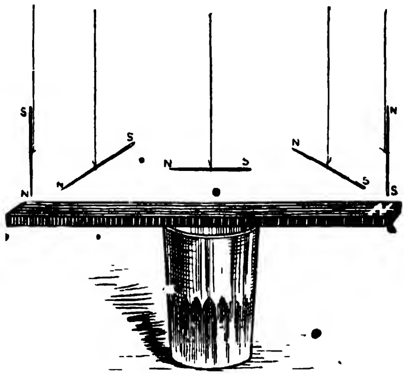
You will readily understand that in this position each pole of the bar magnet attracts an unlike pole of the little suspended magnet, and repels its like pole. The strong magnet is coercing the weaker one; but as it exerts the same influence at both poles, these opposing influences balance one another, so that the needle remains at rest in the horizontal position, and in a line with the magnet below.

Now watch carefully what happens when I move the suspended needle slowly towards one end of the bar magnet.

You observe that when the needle comes to rest, it hangs in the same vertical plane as before, that is, it is still in a line with the magnet below; but one of its poles now points in a slanting direction towards the nearer pole of the bar magnet.

It is clear from this that the stronger magnet, at this pole, is now coercing the weaker one still more.

But watch while I continue to move the needle towards the end of the bar magnet, and you observe



that it begins to slant more and more, as it approaches the pole of that magnet.

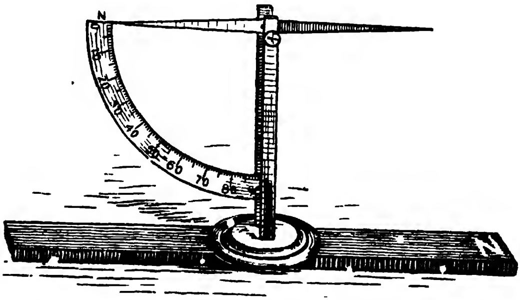
The fact is, the nearer it gets to either pole of the strong magnet, the more it comes under its influence, and at the same time the less it feels the influence of the opposite pole.

Under these conditions one end of the needle is so powerfully influenced that it is compelled to assume a slanting position; and at last when the suspending

thread is exactly over the pole of the bar magnet, the needle hangs vertically, as you now see it.

I need scarcely point out that the results would be just the same if the experiment was repeated at the opposite end of the bar magnet. It would still be a case of the big and strong coercing the small and weak.

These last experiments were intended simply to prepare the way for what is to follow, and our next



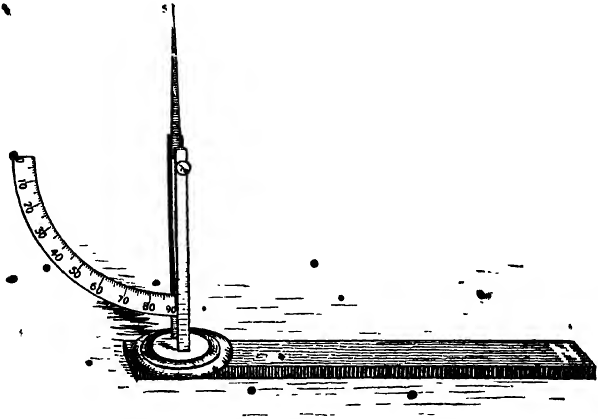
step will be to examine this new instrument, which you can see is another form of magnetic needle.

The magnetic needle, with which you are now quite familiar, is balanced you know on an upright pivot, and consequently it rotates in a horizontal plane. This one, you observe, is suspended on a horizontal axis, and hence it moves only in a vertical plane. Let us see what we can learn about it.

I will stand it exactly in the middle of the bar magnet which lies on the table, with the needle itself at right angles to its neutral line, and you observe that the needle comes to rest in a horizontal position, and in a line with the bar magnet itself. This, you

remember, was exactly the position which the suspended needle assumed, when it was held over the middle of the magnet.

Now observe that, as I move the instrument towards one of the poles of the bar magnet the needle begins to slant, just as the magnetised sewing needle did; and it slants more and more as it nears the end,



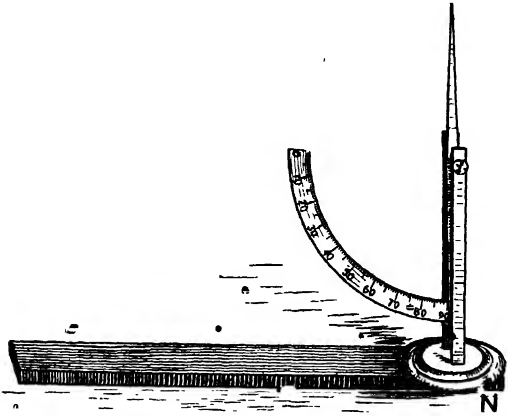
till at last, when it stands over the pole of the bar magnet, it is vertical.

I may now inform you that this slanting of the needle is called magnetic dip, and the instrument itself is known as the dipping needle.

Let us pass on from this to notice the brass quadrant with the angles marked on it. You will at once see the object of this part of the arrangement, if you move the instrument into different positions on the bar magnet. When it is on the neutral line the

needle rests in a horizontal position; but as it is slowly moved towards either pole, the needle begins to dip, and points out on the quadrant the size of the angle which it makes with the horizontal line.

The angle, you see, increases to 10°, 20°, 30°, 40°, 50°, and so on, as the instrument moves, because the needle dips more and more; and when it reaches the



pole, the angle which the needle makes with the horizontal line is 90°, for it is then vertical.

The angle which the dipping needle makes with the horizontal line is known as the angle of dip.

Summary of the Lesson

1. Strong magnets are able to coerce weaker ones.

2. The coercive force of the bar magnet keeps the sewing-needle-magnet horizontal, when it is suspended over the neutral line.

3. The coercive force of the bar magnet causes the sewing-needle-magnet to dip, as it approaches either pole.

4. Each pole of the bar magnet attracts one pole of the smaller magnet, and repels the other.

5. The dipping needle moves in a vertical plane.

6. The angle which it makes with the horizontal line through its centre is called the angle of dip.

Lesson XLII

The Earth a Great Magnet

You remember, of course, that one of our earliest experiments with a magnet was to suspend it in a paper stirrup, and watch till it came to rest; and because we found that it always came to rest with the same end pointing to the north, we learned to call that end of the magnet its north-seeking pole, and the opposite end the south-seeking pole.

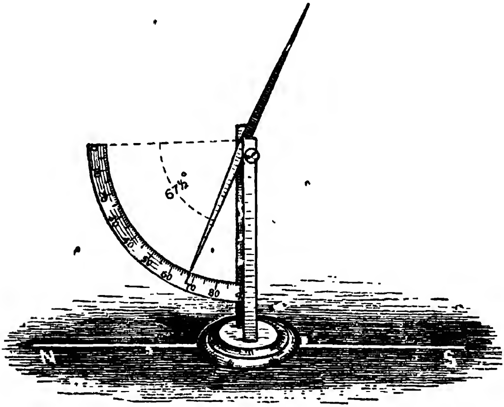
Since then we have watched the magnetic needle oscillate from side to side, while one pole sought the north and the other the south; and we have always observed that when those points are once found it settles, but that it will not rest in any other position.

Our next step must be to find out the reason for all this, and I will commence operations by standing the magnetic needle alone in the middle of the table. Then, if we set it rotating, and watch till it comes to rest, there will be no difficulty in finding its north-seeking pole. Of course the part of the room to which that pole points is the north end, the opposite is the south end.

Well, I will now draw a chalk line across the table to show the direction in which the needle is pointing, and mark one end of the line with N (north) and the other with S (south).

That done, we will remove this needle, and in its place stand the dipping needle, arranging it so that the needle itself shall point directly along the line on the table.

Now watch this needle settle to rest, and see what you can learn from it. It dips, you observe, and comes to rest in a slanting position, making an angle with the horizontal line through its centre, and that angle is shown by the quadrant to be $67\frac{1}{2}°$.



You remember, of course, that we saw this needle dip when it stood on the bar magnet, and that the nearer it approached to either pole of that magnet, the more it dipped, till at last, when it stood immediately over the pole, it assumed a vertical position.

But I need scarcely point out that there is no magnet under it or near it now. Why then should it dip in this way?

This I will now endeavour to explain, and I want you to follow me carefully, for I have a great surprise in store for you.

The line which I have drawn on the table points, as you know, north and south. Now, if we set our faces towards the north, and travelled steadfastly in that direction, we should find, by testing the dipping needle from time to time, that it would dip more and more the farther we advanced.

Look at our dipping needle on the table now, and you will see that it is the north-seeking pole which dips. So it would be in our journey towards the north. That same north-seeking pole of the needle would dip more and more, and at last we should reach a spot where the needle would come to rest in a vertical position, with its north-seeking pole pointing downwards.

You see that the angle which the dipping-needle on the table makes is $67\frac{1}{2}°$. That is the size of the angle of dip for this place, but in lands to the south of us it is a smaller angle. Indeed it gets smaller and smaller as we go south, until there is no angle at all, for the needle comes to rest in a horizontal position.

But if, after this, we continue our journey southwards, we always find that the opposite or south-seeking pole of the needle begins to dip; and it dips more and more, and of course makes a larger and larger angle, the farther we advance in that direction, until in the end a spot is reached where it comes to rest in a vertical position, with its south-seeking pole pointing downwards.

If you have followed this carefully, I think you

will now be ready to draw your own inference that, the earth itself must be a great magnet, and that, like every other magnet, it has its opposite poles, and its neutral line midway between them.

This is perfectly true; indeed it is the surprise which I said I had in store for you, but I wanted you to discover it for yourselves.

The earth is a great magnet, and its opposite poles are known as the north and south magnetic poles.

You have already seen how a big and strong magnet is able to coerce a small weak one; and that will now explain why the magnetic needle points unswervingly in one direction, and why the dipping needle dips more and more as it advances.

The truth is, the earth, as a great and powerful magnet, coerces these small needle magnets, and compels them to act as they do.

The dipping needle, on its journey northwards, continues to dip more and more, until it reaches that spot where it assumes the vertical position with its north-seeking pole pointing downwards, and there it rests because it has at last found what it sought—the north magnetic pole of the earth.

Similarly, when taken in the opposite direction through the southern hemisphere, it at last reaches a spot in the far south, where it again assumes the vertical position, but with its south-seeking pole this time pointing downwards; and it comes to rest in that position, because it has there found what it sought—the south magnetic pole of the earth.

Summary of the Lesson

1. A dipping needle at the north magnetic pole settles in a vertical position, with its north-seeking pole pointing downwards.

2. The same needle at the south magnetic pole settles in a vertical position, with its south-seeking pole pointing downwards.

3. The angle of dip in England is 67½°; it increases as we proceed farther north.

4. The earth, as a great magnet, coerces the dipping needle, and compels it to dip.

5. The earth as a great magnet, has its two opposite poles, like any other magnet.

6. One of these is called the north magnetic pole; the other the south magnetic pole.

Lesson XLIII

The Earth's Magnetic Poles

Our lesson to-day must be a mixture of geography and magnetism, for I shall have to direct your attention to some familiar facts, which you have learned in your geography lessons.

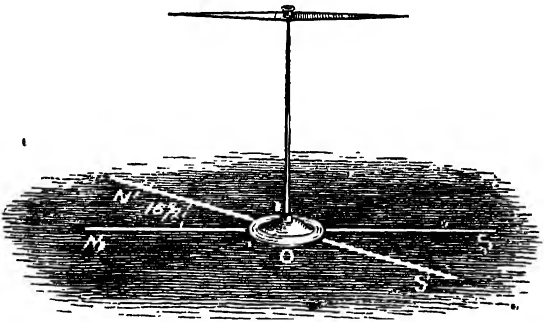
To begin with, then, you know that at noon, or mid-day, the sun is due south, and that if a person at that time of the day turns his back to it and walks in a direct line forward, he is moving towards the north.

The straight line along which he walks stretches due north and south, and these points of direction found by means of the sun at noon are usually known as the geographical north and south, or the true north and south.

Your own geography lessons have long ago made you familiar with the north and south parts of this room, and you remember that, in finding them, we always take the sun as our guide.

Hence it is clear that these north and south points, as you already know them, are the true or geographical north and south.

Let us make a chalk mark on each of the two opposite walls, to show the positions of the true north and the true south. Then, if I stand the magnetic



needle on the table, and leave it to come to rest, you will at once see that the line between the true north and the true south does not correspond to the line which the needle indicates.

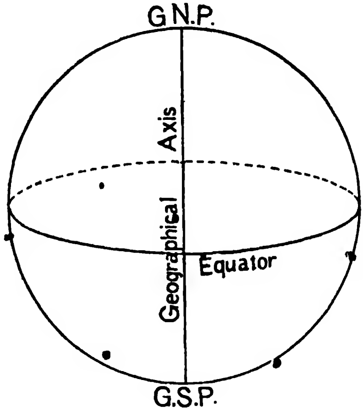
It is clear from this that the magnetic north and south poles are not the same as the geographical north and south poles.

Now for the next step. I will draw a chalk line across the table in the direction which the magnetic needle indicates, and mark one end of it N (north), the other S (south). Then I will cross it, at the

point O where the needle stands, with another line N′OS′, making an angle N′ON exactly $16\frac{1}{2}°$.

That done, I want you to look straight along this last-made line, and you will discover that one end of it points to the true north, the other to the true south, that is, to the marks on the two opposite walls.

We have found, as you now see, the true north and south by observation of the sun, and also by means of the magnetic needle, and the result is the

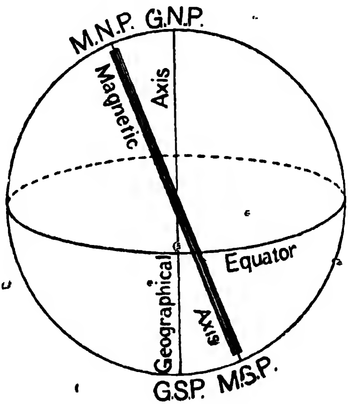


same in both. The letter N′ points to the geographical or true north pole; the letter N points to the magnetic north pole.

Now for some more geography. This circle which I have drawn is meant to represent our globe, with its north and south geographical poles, N and S. The line between the two poles is to represent the earth's axis, and the circle which passes round the globe midway between the poles is the equator.

Now careful research has proved beyond doubt that the magnetic north pole is situated, not at the true or geographical north pole, but some distance from it, in the Boothia Promontory, in the northern part of North America.

If then, starting from that spot, we imagine a straight line through the centre of the earth to a similarly-placed spot in the southern hemisphere, we



shall have another axis, and that we shall henceforth call the earth's magnetic axis.

Here it is in the sketch, with the magnetic north and south poles at its opposite ends.

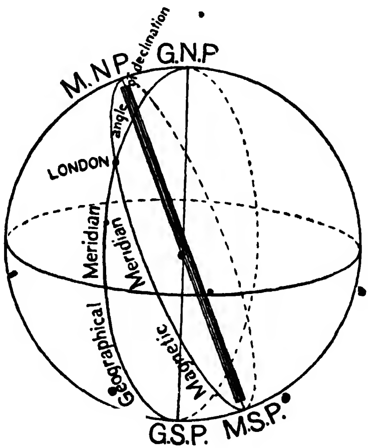
Then, as the next step, let us take one or two other geographical terms, which of course are quite familiar to you.

You know that the part of the sky which is exactly overhead is called the zenith; and you also know that the imaginary line, which is supposed to stretch between

the north and south poles and through the zenith is called the meridian.

I need scarcely point out that every spot on the earth's surface has its zenith, and therefore its own meridian.

The meridian of a certain place is really part of a great circle, which stretches through the zenith of that place to both geographical poles, and so on round the



earth; and as this meridian passes through the geographical north and south poles, we may call it the geographical meridian.

Let us now indicate the position of London on our sketch by a dot. Then if through this dot we draw a curved line to both geographical poles, we shall have a representation of the geographical meridian of London.

But I must now point out that, just as every place

has its geographical meridian, which passes through the geographical poles, so also it has its magnetic meridian, which passes through the magnetic poles.

If then I draw another curved line through London to the north and south magnetic poles, this will represent the magnetic meridian of that place.

You observe that these two meridians, the geographical and the magnetic, cross each other at an angle. This angle is known as the angle of declination, because it shows how far the magnetic north declines, or falls away, from the true north.

If the angle between the two meridians of London is measured, it is found to be $16\frac{1}{2}°$. Hence the angle of declination for London is said to be $16\frac{1}{2}°$.

This explains why, in our last experiment, we measured an angle of $16\frac{1}{2}°$ on one side of the magnetic meridian, to help us in finding the geographical meridian.

You must bear in mind, however, that every spot on the earth's surface has its own geographical and magnetic meridians, and that they must, of course, cross at varying angles, so that the angle of declination varies between one place and another.

Summary of the Lesson

1. The magnetic poles are not the same as the geographical poles.

2. The magnetic north pole is situated in the Boothia Promontory in North America.

3. A line from this pole through the centre of the earth is the earth's magnetic axis.

4. The angle formed by the crossing of the geographical meridian of a place and its magnetic meridian is called the angle of declination.

5. This angle shows the difference in degrees between the position of the true pole and that of the magnetic pole at that particular place.

6. The angle of declination for London is $16\frac{1}{2}°$; but the angle is not the same in all places.

Lesson XLIV

The Mariner's Compass

Our recent study of the earth as a great magnet, with power to influence and coerce other magnets, now leads us by a natural step to investigate the mariner's compass, one of the most useful contrivances ever invented.

But before proceeding to examine the actual instrument, I may point out that the word compass means a circle. If then you note the circular shape of the box itself, and the circular card which moves round inside it, you will at once see that it is called a compass because it works in a circle.

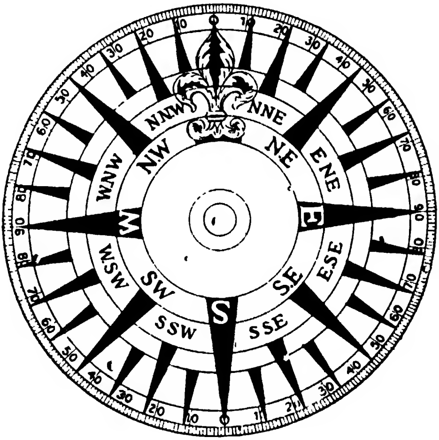
I need scarcely explain why it is called the mariner's compass, because you all know it is used by mariners or sailors, as a guide to help them in steering their course at sea. There is another form of compass, which is used by persons who travel on land, and that is known as a land compass.

Now let us proceed with the instrument itself, and probably the first part of it to catch your eye will be the card with its letters and pointers, which can be plainly seen through the glass cover.

A card similar to this, but larger, has been familiar to you from your earliest lessons in geography as the

Points of the Compass. We will examine this compass card more fully now, and you will find that it is exactly the same. It is your old friend, the Points of the Compass.

Observe, in the first place, that it is divided into four quadrants by two diameters which cross each other at right angles, and that the extremities of these diameters give the four cardinal or chief points, —north, south, east, west.



These, as the chief points, are more distinctly marked, you see, than the rest; and north is specially designated by a fleur-de-lis.

Then, you observe in the next place, that the four right angles formed by these diameters are bisected by two other diameters, whose extremities give four intermediate points—north-east (N.-E.), midway between north and east; north-west (N.-W.), midway between north and west; south-east (S.-E.), midway between

south and east; and south-west (S.-W.), midway between south and west.

It is not at all necessary, or even advisable, to trouble you now with the names and particulars of the remaining points. It will be quite sufficient for you to observe that all of them are obtained by the bisection of angles already formed.

In all there are thirty-two points marked on the compass card at equal distances apart, and when we speak of the points of the compass we refer to these thirty-two points.

You will now observe that if I stand the model in different positions on the table, the card begins to oscillate from side to side every time it is moved; but it always settles to rest at last with the fleur-de-lis and the letters and pointers round it in the same position.

The card, as you may see for yourselves, is only paper, for cardboard is made of paper. Why then should this paper card always settle in one position?

We shall best answer this question by lifting the glass cover from the box, and removing the card for closer inspection.

If you turn the card over, you will see that there is a thin flat strip of steel attached to the under side of it; and you will also see that both are securely fixed together, so that one cannot move without the other.

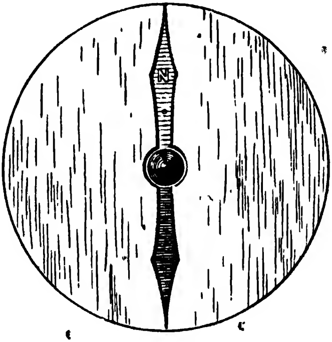
You observe, too, that at one end of the steel bar is the letter N; and a glance will show you that this letter N is immediately under the peculiar fleur-de-lis mark on the upper surface of the card.

Notice next, that in the centre of the steel bar is a

small hollow cap. This is commonly known as the agate cap, because the bottom of the hollow is fitted with a piece of agate, and it is this which rests on the upright steel pivot, which you see in the middle of the box.

The rest of course is easy. The piece of steel is a magnet, and when it is balanced on the steel pivot it is free to move in a horizontal plane.

Like every other magnet which is free to move, it points with its north-seeking pole to the magnetic



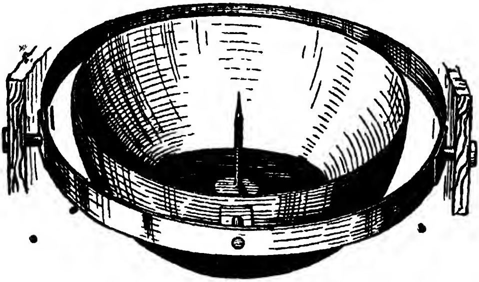
north pole of the earth; but when it moves it must carry the card round with it, because both are fixed together.

I need scarcely say that the magnet is the most essential part of the whole contrivance, and it is known as the compass needle. The land compass, of course, has its compass needle too, but the card, instead of being attached to it, is fixed to the bottom of the box, and the needle alone moves round on its pivot.

Now for a few words about the box which holds

the needle and card. You observe that it is a round bowl-like case, in the centre of which stands the upright spike or pivot on which the needle rests, and that it is securely closed by a tight-fitting glass cap, so that the card can be plainly seen without being exposed.

It is important to notice, too, that the case and everything belonging to it, except the glass cover, is made of brass, not steel or iron; and no doubt you will at once see the reason for this. Brass is not a



magnetic substance. It does not affect the needle in any way.

Iron or steel would be unsuitable, because they are magnetic substances, and would attract the magnet, and so make it useless for its purpose.

We shall have something more to say about the mariner's compass later on.

Summary of the Lesson

1. The compass card is divided into 32 equal divisions, and the pointers which make these divisions are known as the points of the compass.

2. The four principal ones are called the cardinal points.

3. In the mariner's compass the compass needle is fixed to the under side of the card, so that the card must move with the needle.

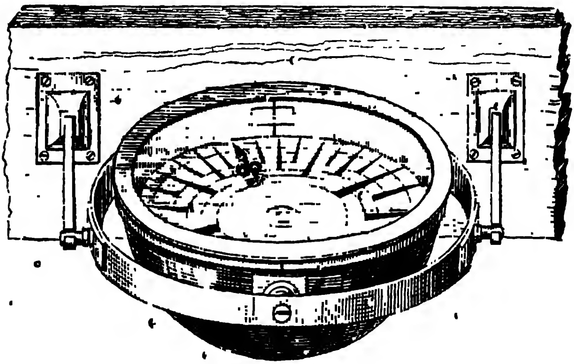
4. In the land compass the card is fixed, and the needle moves on a pivot above it.

5. The box of the compass is made of brass, and the pivot is fixed exactly upright, and in the centre.

Lesson XLV

The Compass at Work

We will have another look at the mariner's compass to-day, but this time we shall confine our attention to



the brass bowl or case, which holds the all-important needle and card.

Before we turn to the instrument itself, however, let me remind you that it is intended for use on board ship, and that ships on the sea roll and pitch in every direction with the force of the waves.

If the compass were allowed to roll with the ship, the needle and card would not be free to move, for they would be constantly coming into contact with some part of the case itself.

It is only by keeping the case horizontal, that the needle can be left free to move.

Now take the model in your hand, and tilt it in different directions, and you will observe that, in every position, the bowl itself and the card inside it are kept horizontal, in fact, they cannot slant.

Let me show you how this is brought about.

In the first place, then, I must call your attention to this flat brass ring which surrounds the box. The

box itself, you observe, is fitted with two pivots, one exactly opposite the other, and each pivot works easily in a small round hole in the brass ring.

Then you observe further, that the ring, in its turn, moves on similar pivots, which are placed at right angles to the others, and work in small slots in the side supports.

By this arrangement, when the instrument is tilted in one direction its box swings on the ring, and when it is tilted in a direction at right angles to that, the ring and the box with it swing on the side supports; so that in either case the compass needle and card preserve their horizontal balance.

The brass ring and its pivots are known as the gimbals, and without this clever contrivance the compass would be of no use on a rough sea.

The ship's compass, you know, is always lodged in a protecting case, called the binnacle which, like the compass box itself, is made of brass, and of course for a similar reason.

The binnacle too is made a fixture to the deck, or some other part of the ship, and the top of it is closed and protected with a plate of thick glass.

And now lastly let me call your attention to the plainly-cut mark on the edge of the compass box. In fixing the compass to the ship, great care has to be taken to see that the straight line from this mark, through the centre of the card, is exactly in the direction of the ship's keel.

In other words, the mark itself must point to the head of the ship, and the opposite end of the line to the stern.

When the man at the wheel is told by the captain

to steer N.-E., he turns the ship about, till the north-east pointer on the compass card points in the direction of the line and the plainly-cut mark at its end.

One other important matter must be made clear before we leave this subject.

You remember, of course, that the compass needle points out the magnetic north. But I need scarcely remind you that the sailor, for the purpose of steering his ship, must know the true north.

The difference between the magnetic north and the true north, you know, is called the angle of declination, and this angle is not the same in all parts of the world.

That seems at once to give rise to a great difficulty, but the difficulty is obviated by supplying all ships with a book of tables, showing the declination of different places.

The sailor finds the direction as indicated by the compass, and then adds or subtracts the angle of declination, as his book of tables directs him, and this gives him his true course.

Summary of the Lesson

1. The box of the compass is made of brass, and the pivot is fixed exactly upright, and in the centre.

2. The gimbals provide for the rolling of the ship, and keep the compass itself horizontal.

3. The man at the wheel has to make allowance for declination in steering the ship.

4. When he has found on the compass card the direction he wishes to take, he turns the ship about till that point is in a direct line with her keel.

Lesson XLVI

Electric Attraction

No doubt you are all familiar with the peculiar yellow, semi-transparent substance called amber; and you know it is mostly seen either in the form of pipe-stems for smokers, or else as brooches and other ornaments for the person.

Take a piece of this substance, and rub it vigorously with a piece of flannel, or on your coat sleeve, and then bring it near some loose scraps of paper or little pieces of straw.

You will at once observe that the amber has now a strange attractive force which it did not possess before, for it attracts those little particles of paper and straw, and makes them fly up towards it. The newly-acquired force is clearly the result of the rubbing.

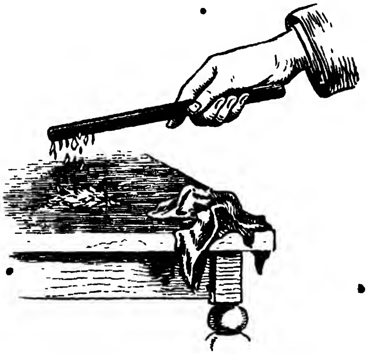
This peculiar substance—amber—is of vegetable origin, and is supposed to be the fossilised resinous gum of some extinct species of pine. Beds of amber are found in the earth in certain parts of the world, and the substance has been known for thousands of years.

Indeed the ancient Greeks of 2500 years ago were very fond of amber ornaments, and they observed that when these ornaments were rubbed (probably in cleaning them) they acquired a new and mysterious power of attracting light bodies.

The Greek name for amber is electron, and that word has given us our name for the hidden force itself, which we call electricity.

You, of course, remember that a steel knitting-needle, or indeed any piece of iron or steel if rubbed with a magnet, acquires a new force, which we call magnetism; and now we find that amber when rubbed produces similar results.

Let us, however, compare the rubbing in the two cases. We simply stroke the needle with the magnet a few times in one particular direction. But the amber must be rubbed vigorously, and as the vigorous



rubbing causes friction, we usually speak of the force produced in this way as frictional electricity.

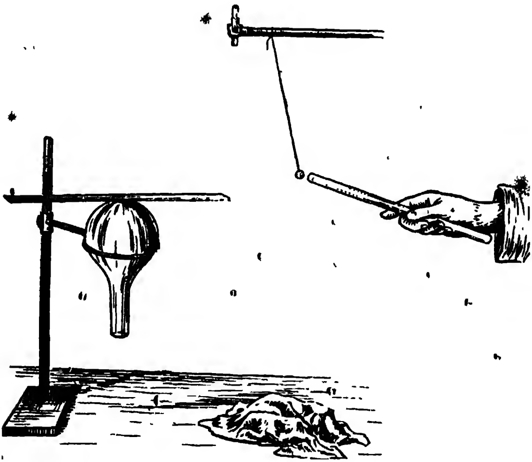
Amber, however, although it has given the name to this wonderful force, is not the only substance which acquires it with rubbing.

Resin, sealing-wax, shellac, vulcanite, and roll-sulphur all acquire electric force, if rubbed with a dry warm flannel, or other woollen rubber.

After rubbing, each of these substances causes loose light scraps of paper or straw to fly up towards it, for each of them, when rubbed, possesses the same attractive force as the rubbed amber.

Warm a piece of brown paper in front of the fire, rub it briskly with the bristles of a stiff clothes-brush, and then hold it over your head, and you will observe that it will cause your hair to stand on end.

Like the other things, the paper acquires attractive force by rubbing, and this is clearly seen if it is placed against the wall or a drawing-board, for it clings fast. These little experiments you can perform for yourselves at home.



Let me now show you another. I will suspend this small pith-ball by a cotton thread from the gas-pipe, and at the same time balance this thin, flat, wooden lath on the round bottom of an inverted flask.

Now I will rub this glass rod briskly with a warm, dry, silk pad, and bring the rubbed end near the pith-ball and the lath in turn. The pith-ball is at once attracted to the glass rod, and clings to it; and the

wooden lath is also attracted, and follows where the glass leads. Hence it is clear that glass, like amber, sulphur, resin, sealing-wax, and the rest, acquires attractive force when it is rubbed.

It is most important to remember, however, that these things in their natural state had no more power than the poker possesses to attract the pith-ball, the lath, and the loose scraps on the table. It was only after the rubbing that they exhibited this wonderful attractive force, which we call electricity.

Each one was excited by the rubbing, and in that state it is said to be electrified. The rubbing in fact gave to each a force which it did not originally possess, and hence we speak of it as a charged body. It is charged with a new force.

Hence each of these substances, before it is excited or electrified by the rubbing, might be described as an uncharged body.

Just one thought more before we close. You know that after a bar of steel has been rubbed with a magnet it becomes a magnet itself, and the magnetic force given to it by the rubbing is permanent. It is not so with the electric force given to these bodies by rubbing. The excited body gradually loses its charge, and is no longer able to attract the pieces of paper, or to move the pith-ball or the wooden lath.

The charge passes away from some bodies more quickly than from others, and none of them can retain it long.

Summary of the Lesson

1. The force which we know as electricity was so called from electron, the Greek name for amber.

2. As the force is produced by rubbing, it is known as frictional electricity.

3. Resin, sealing-wax, shellac, vulcanite, and roll-sulphur develop the same attractive force as amber does, when they are rubbed with a woollen rubber.

4. Glass acquires attractive force when it is rubbed with silk.

5. A body which has been excited by rubbing is said to be charged or electrified.

6. The charge given to a body by rubbing is not permanent, like that of a magnet.

Lesson XLVII

Attraction and Repulsion

If you think over our experiments in the last lesson, you will remember that the glass rod, shellac, sulphur, sealing-wax, and vulcanite in their natural state had no attractive force.

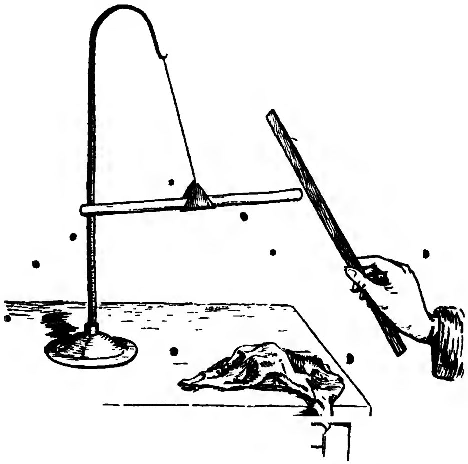
They received the electric charge as the result of the rubbing, and in that state they were able to attract the pith-ball, the lath, and the loose scraps on the table.

I need scarcely remind you that the pith-ball, the lath, and the other things were in a natural or uncharged state, for they had not been excited; and it is clear from this that in each case the charged body attracted an uncharged body.

Now let us take another step. I will rub the glass rod briskly with the warm silk rubber as before, and place it in the stirrup. Then if I bring the wooden lath near, you observe that the charged glass rod is attracted by the uncharged lath.

The result will be the same if you hold your finger near the glass rod. The uncharged hand attracts the charged glass rod. Hence we have clear evidence that the attraction between charged and uncharged bodies is mutual. A charged body attracts, and is attracted by, an uncharged body.

We will now rub the glass rod vigorously again with the warm silk, and replace it in the stirrup. Then, if we charge the vulcanite rod by rubbing it with fur or flannel, and bring it near the glass, you



observe that the charged vulcanite attracts the charged

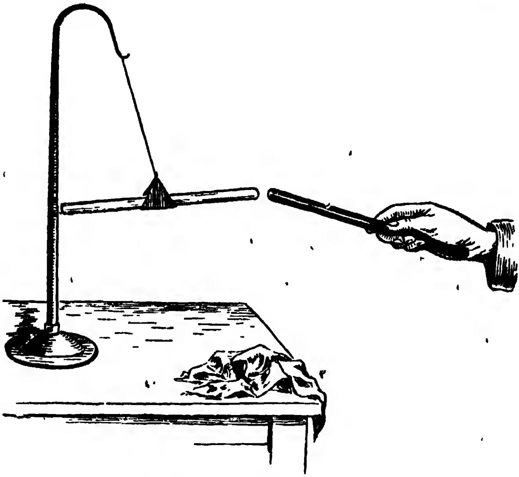
The same result will follow if we substitute sealing-wax, shellac, and sulphur rods for the vulcanite. Each of these bodies when charged attracts the charged glass rod.

Now let us reverse the process by charging the vulcanite, shellac, sealing-wax, and sulphur as before,

and placing them in the stirrup one by one. If the charged glass rod is brought near each of these charged bodies, attraction will take place.

It is clear then that a charged glass rod attracts, and is attracted by, charged rods of vulcanite, sulphur, shellac, and sealing-wax.

Now for the next step. I will rub the glass rod once more with the warm silk, and place it in the stirrup as before. Then if I charge another glass rod



CHARGED RODS OF GLASS AND VULCANITE.

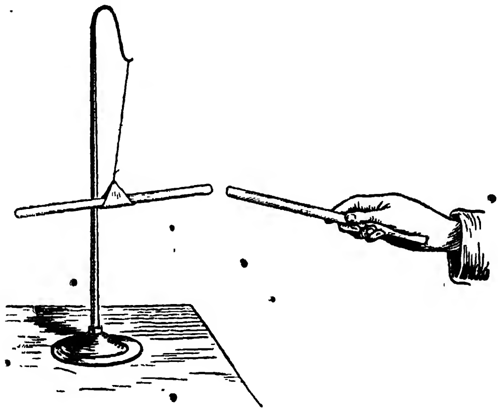
in the same way, and bring it near, you observe that the suspended rod moves away from the other.

Both were charged in precisely the same way, so that the charge given to the suspended rod is exactly like that given to the other; and these like charges repel one another.

If we repeat the experiment with two charged

vulcanite rods, suspending one and bringing the other near it, you observe that the result is the same. The charges given to the two rods are exactly alike, and these like charges repel one another.

So it would be if we charged the sealing-wax, shellac, and sulphur rods, and presented them to the charged vulcanite in the stirrup. In every case repulsion would follow.



TWO CHARGED GLASS RODS.

Now let us sum up what we have learned from all this.

Glass rubbed with silk repels glass rubbed with silk.

Vulcanite rubbed with fur or flannel repels, and is repelled by vulcanite rubbed with fur or flannel.

Vulcanite rubbed with fur or flannel repels, and is repelled by, sealing-wax, shellac or sulphur, similarly charged.

Glass rubbed with silk attracts, and is attracted by,

vulcanite, sealing-wax, shellac, and sulphur rubbed with fur or flannel.

The charge which is given to glass by rubbing it with silk is called positive electricity; that which is given to vulcanite, sealing-wax, shellac, and sulphur, by rubbing them with fur or flannel, is known as negative electricity.

If you remember this you will have no further difficulty in understanding the general laws.

A body charged with positive electricity repels a body charged with positive electricity.

A body charged with negative electricity repels a body charged with negative electricity.

A body charged with positive electricity attracts, and is attracted by, a body charged with negative electricity.

You remember, of course, the general law in magnetism, that *like poles repel, unlike poles attract*; and you see from this that in a similar way we can put the above laws briefly, as regards the force of electricity, by saying that *like charges repel, unlike charges attract.*

Now, I daresay, you have been wondering why it is that a charged body attracts another body. Let me explain.

A body before it is charged or electrified contains both kinds of electricity, but they are in equal quantities, so that they neutralise each other and are dormant, and the body itself is said to be in a neutral state.

The rubbing separates the positive electricity from the negative. In one case it leaves the positive on the rubbed body, and we say that body is charged

with positive electricity. In another case it leaves the negative on the body, and then we say that the body is charged with negative electricity.

The one thing to remember is that, in any case the charged or excited body is in an unnatural state, and that Nature is constantly striving to restore the balance—to make it neutral once more.

It is clear that a positively charged body can only become neutral by exchanging some of its positive electricity for an equal quantity of negative, and a negatively charged body can only become neutral by exchanging some of its negative for an equal quantity of positive.

This explains the eagerness of every electrified body to attract to itself the opposite kind of electricity to that with which it is charged.

SUMMARY OF THE LESSON

1. A charged body attracts and is attracted by an uncharged body.

2. A glass rod rubbed with silk attracts and is attracted by rods of vulcanite, sulphur, shellac, and sealing-wax, rubbed with fur or flannel.

3. Glass rubbed with silk repels glass rubbed with silk.

4. Vulcanite rubbed with fur or flannel repels and is repelled by vulcanite, sealing-wax, shellac, or sulphur similarly excited.

5. The charge given to glass by rubbing it with silk is known as positive electricity.

6. The charge given to vulcanite, sulphur, shellac or sealing-wax by rubbing any of them with fur or flannel is called negative electricity.

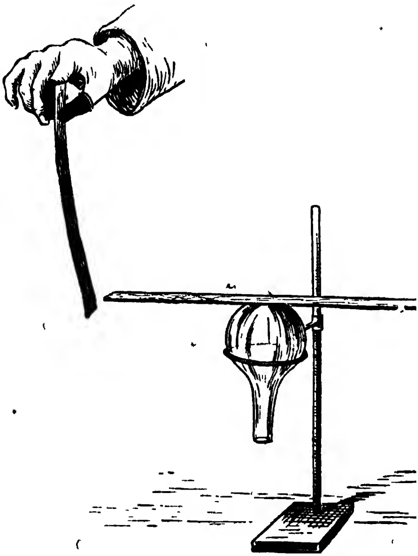
7. Like charges repel; unlike charges attract.

8. A charged body is in an unnatural state; its great aim is to become neutral again.

Lesson XLVIII

The Electroscope

As a natural connecting link between the teaching of last lesson and what is to follow, we will commence



this time with a very simple experiment, which you can afterwards perform for yourselves.

I have here two pieces of vulcanised india-rubber tubing, which I will place on my thumb and fore-finger, to act as finger-stalls, and then I will draw this silk ribbon between them three or four times.

Now observe what happens when I bring the

ribbon near the balanced lath. The ribbon, you see, attracts the lath and makes it move. Can you explain this?

Yes, you are quite right. The wooden lath is a neutral or uncharged body, the ribbon has been charged with electricity by the rubbing, and the charged body attracts the uncharged body.

But now observe further that, if I hold the ribbon near the wall, it clings fast. I need scarcely point out that this time it is the charged body which moves, not the uncharged body. How do you account for that?

Ah! I am glad to find you have not forgotten. A charged body not only attracts, but is also attracted by an uncharged body. This time the neutral or uncharged wall attracts the charged ribbon, and makes it cling fast.

Now let us take another step. I will repeat the process of drawing the ribbon between the india-rubber finger-stalls a few times, and then I want you to observe what happens when I fold it across the middle, and let the two ends hang loose.

The loose ends, you see, spread out away from each other. What can be the meaning of this?

The ribbon has been charged with electricity by the rubbing as before, and both parts of it received the same kind of charge from the same source. Why do the ends spread out in this way?

Yes, you are quite right once more. The similarly charged ends repel each other, because like charges repel, and unlike charges attract.

Now as the next step, let me introduce to you this curious but useful instrument—the electroscope.

I shall content myself for the present with pointing out the brass cap on the top, and the two strips of gold-leaf hanging inside the glass vessel, and I may at

once tell you that the instrument is usually called the gold-leaf electroscope.

I need scarcely remind you that the contrivance, and everything belonging to it, is at present in a neutral or uncharged state; and you see that the gold-leaves hang parallel side by side.

I will now charge the glass rod slightly by rubbing it with the warm silk rubber, and I want you to

observe what happens when I touch the cap of the electroscope with the charged end.

The leaves at once fly apart, just as the ends of the ribbon did. But why do they fly apart?

Yes, I see you are eager to tell me. They fly apart because both are electrified by the same charge, and like charges repel.

That is quite right; the gold leaves have been charged; but they were not charged by rubbing, as the ribbon was. How then did they receive their charge?

The charge was transmitted to the leaves when the electrified glass rod touched the brass cap. The cap received the charge from the electrified rod, and conveyed it to the leaves; and this makes it clear that a body can be charged by mere contact without any rubbing.

A body which conveys electricity to another body in this way is called a conductor, and the electricity is said to travel along it by conduction. Hence the brass cap which conveyed the electricity from the glass rod to the leaves is a conductor.

This is all the notice we need take of the electroscope for the present; we shall deal with it more fully later on.

Summary of the Lesson

1. The leaves of the electroscope diverge because they are both electrified by the same kind of charge.

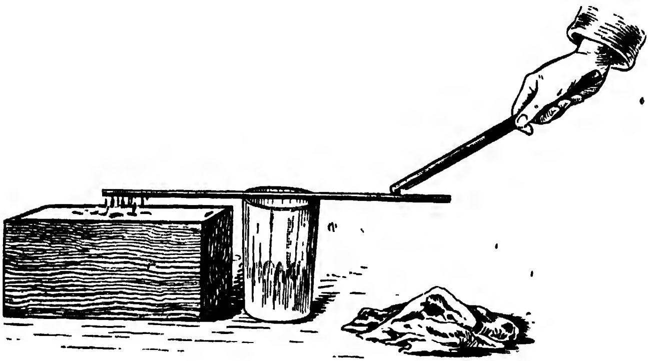
2. A body can be charged by mere contact with a charged body.

3. A body which conveys electricity to another body by contact is said to be a conductor.

Lesson XLIX

Conductors and Insulators

We learned from the last lesson that electricity can pass from one body to another by mere contact; that the body which conveys a charge in this way is called a conductor; and that the electricity so con-



veyed is said to travel by conduction. Now let us go a step further.

I will support this brass rod on a tumbler, and immediately under one end of it I will place a few small scraps of gold-leaf on a pile of slates. That done, I charge the vulcanite rod by rubbing it vigorously with fur or flannel; and I want you to observe what happens, when I stroke the opposite end of the metal rod with it.

You see that, as the metal rod is stroked at that end, the pieces of gold-leaf are attracted at the other;

and it is clear from this that, in the first place, the charge must have passed from the vulcanite to the brass, when the two things came in contact, and secondly, that the electricity conveyed in this way must have travelled from one end of the rod to the other.

This, of course, is a further proof that brass is a conductor, and that electricity travels along it by conduction; but I may now inform you that all metals are conductors of electricity.

Let us in the next place repeat the experiment, substituting for the metal bar a neutral glass rod.

I proceed exactly as before; but this time you observe that there is no attraction—no sign of any movement whatever among the pieces of gold-leaf at the opposite end of the glass rod, as the result of the stroking.

Hence it is clear that electricity does not pass from the charged rod along the glass, as it did along the metal. The metal allows the electricity to flow along it, but glass resists the flow, and will not allow the electricity to pass. For this reason glass is said to be a non-conductor.

If we repeat the experiment again, substituting in turn neutral rods of vulcanite, shellac, and sealing-wax for the glass, it will be clearly seen that all these are like glass. They resist the flow of electricity, and hence they, like glass, are all non-conductors.

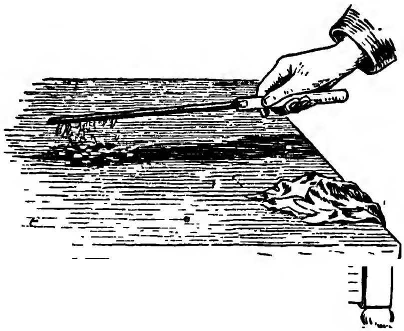
Here I have a brass rod fitted into a glass tube, which serves as a handle. Let us have another experiment.

Take the glass handle in one hand, and with the other rub the brass rod itself vigorously with the warm

silk rubber. When that is done bring the charged end near the pieces of gold-leaf on the table, and you will observe the attraction which follows. The little scraps of gold-leaf instantly fly up towards the metal rod.

Now hold the rod nearer the middle, so that the thumb, or some part of the hand, touches the brass, and then repeat the experiment.

This time you observe that, after the most vigorous rubbing, there is no movement at all among the scraps of gold-leaf. When the metal rod is brought near, it



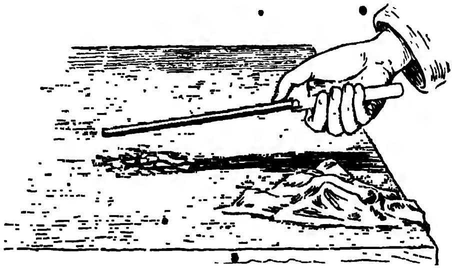
has no longer any attractive force for them. This is a bit of a puzzle; let us see if we can solve it.

Glass, you know, is a non-conductor, and resists the flow of electricity. When, in the first experiment, you held the rod by the glass handle, the electricity remained on the metal, because it could not escape, and it was able to attract the little pieces of gold-leaf.

But the puzzle is in the second experiment, where we found it was impossible to charge the metal rod with all our rubbing.

You remember that this time, although you held the rod by the glass handle, your thumb rested on the metal itself. Well, that is the whole secret, for all the time your hand touched the metal, the charge escaped, as quickly as it was generated by the rubbing.

What do you say? Your hand must be a conductor? Why, so it is, for the electricity flowed along the hand from the metal rod.

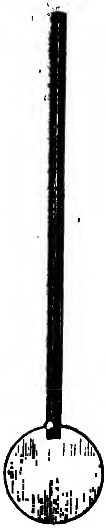


The hand which touched the metal conducted the electricity away, and it passed through your body. But what became of it at last?

Let me explain. The earth itself is the great reservoir of electricity, and all electricity which is conducted or carried off through our bodies in this way returns to it. That is to say, the charge which was given to the metal rod by the rubbing, was conducted away from it by the hand, and so through the body to the earth as the great reservoir of electricity.

And now let me call your attention to the rod itself once more.

I hold it by the glass handle, and charge it as before by rubbing it with the warm silk rubber, and



you know that the charge is there, because if you bring the metal end of it near the scraps of gold-leaf, attraction immediately takes place.

But I want to point out to you now that the electricity on the metal cannot escape; it is cut off by the non-conducting glass handle from all connection with other bodies, as completely as an island is cut off by the water which surrounds it from connection with other land.

Hence the non-conducting body—glass—is said to be an insulator, from the Latin word *insula*, which means an island.

The proof-plane, a little instrument used for testing small charges of electricity, is made on this principle. It consists of two parts—a disc of metal, or some other conducting substance, and a handle made of non-conducting material for insulating it.

Any boy can make one for himself with a penny for the disc, and a stick of sealing-wax for the handle.

Summary of the Lesson

1. All metals are good conductors.

2. Glass, vulcanite, shellac, sealing-wax, and sulphur are non-conductors.

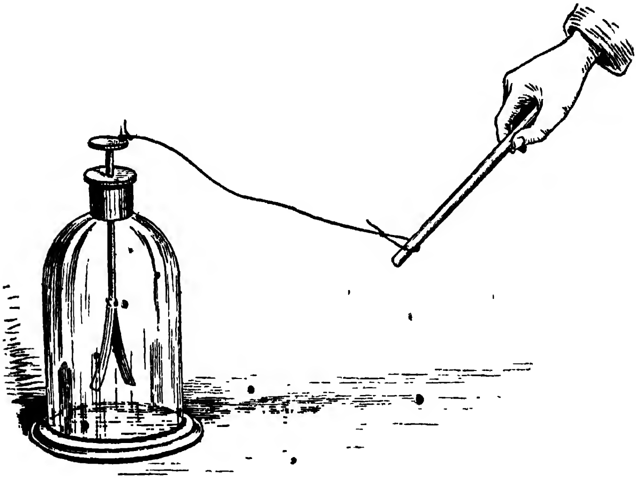
3. An insulator is a non-conducting body, which, electrically speaking, cuts a charged body off from everything around it by obstructing the flow of its electricity.

4. The proof-plane consists of a conducting disc and an insulating handle.

Lesson L

MORE ABOUT CONDUCTORS AND INSULATORS

Of course you now clearly understand the meaning of the terms—conductor and non-conductor; and you



also know that the metals are the best conductors of electricity, while glass, vulcanite, shellac, and sealing-wax are non-conductors. The next step will be an easy one.

I will fasten one end of this copper wire to the cap of the electroscope, and bend the opposite end round to form a loop. Then I will pass the loop over the glass rod, and hold it at the lower end with my

thumb, while I charge the rest of the rod by rubbing it with the warm silk rubber.

Now observe what happens when I lower the rod, so as to cause the loop to slip down towards the charged end.

Immediately the loop reaches the charged part of the rod, the leaves of the electroscope diverge.

Yes, I thought you would be able to explain it. The charge which is given to the rod by rubbing passes along the wire to the electroscope, because copper is a conductor.

Now I will repeat the experiment with a thread of dry silk in place of the wire, and you observe that, however strongly the rod is charged, there is no movement in the leaves of the electroscope when the silk loop slips down.

It is clear, then, that electricity will not pass along the silk.

But we have not done yet. I will wet the silk, and try again in exactly the same way as before, and this time you observe that the leaves of the electroscope diverge as soon as the loop of wet silk slips down to the charged end of the rod.

The dry silk, you see, obstructs the flow of electricity—it is a non-conductor. But when it is wetted it becomes a conductor, and it is quite clear that its power of conducting electricity is due to water.

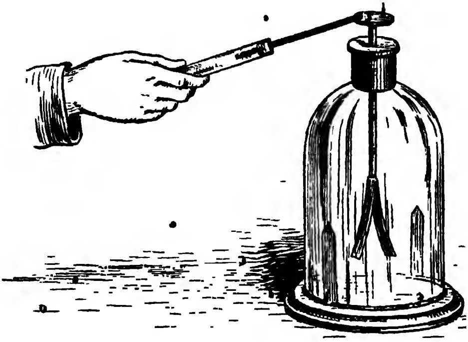
Water, in fact, is a good conductor of electricity, and that explains why, in all our experiments, it is necessary to keep everything we use perfectly dry. If there is the least moisture on any of the articles, it will conduct the electricity away.

For the same reason it is practically impossible to

perform any experiments successfully on a wet or foggy day, because the moisture in the air conducts the electricity away as quickly as it is produced.

Damp air is a conductor; dry air is a non-conductor.

Now let us have another experiment. We will fit a cork in one end of this glass tube, and insert a pen-holder into the cork. Then, after charging that end of



the tube in the usual way, I will touch the cap of the electroscope with the free end of the wood.

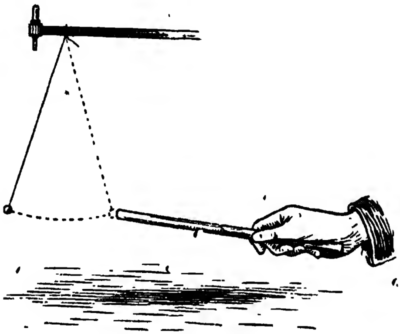
You observe that the leaves at once diverge, showing that the charge which was given to the glass has passed along the wood to the electroscope.

But the wood itself, as you can see, does not touch the glass. Hence it is clear that the charge must pass along the cork before it can reach the wood, and from this we learn that cork and wood are both conductors.

Here is another little experiment, which you can do for yourselves.

Suspend a pith-ball by a dry silk thread from the gas-pipe, and then bring the charged glass rod near it. You observe that the pith-ball is at first attracted to the rod, but that as soon as they touch, it flies back, and after that, if the rod advances the ball recedes. In other words, the glass constantly repels the pith-ball now, instead of attracting it.

If you repeat the experiment with another ball at the end of a cotton thread, you find that the ball flies



at once to the glass rod, and clings fast to it. This looks like a puzzle; let us try to unravel it.

What is the condition of each ball at first? It is neutral.

What does that mean? It means that the ball contains equal quantities of positive and negative electricity.

What is the condition of the excited glass rod? It is charged with positive electricity.

Why does it attract the ball? Because it is seeking for negative electricity to restore the balance, so that it may become neutral again.

What happens when the ball touches the glass? The glass gives up some of its positive electricity to the ball, and robs the ball of all its negative.

What is the condition of the ball then? The ball, like the rod, is then charged with positive electricity.

What have we just been learning, about dry silk? Dry silk thread is a non-conductor.

Exactly: now think of the pith-ball charged with positive electricity by coming into contact with the charged glass rod. The charge which has been given to it cannot escape; it is insulated by the non-conducting silk thread.

Hence repulsion now takes place between the rod and the ball, because both are charged with positive electricity, and like charges repel.

But the other ball at the end of the cotton thread also gave up its negative to the rod, and received positive from it in exchange, and yet it constantly clings to the glass. Why is this?

That ball, after contact with the rod, is charged with positive electricity; but like all other charged bodies, it will get rid of this charge if it can, in order to become neutral again.

The cotton thread, unlike the dry silk, is a conductor, and allows electricity to flow along it without obstruction. Hence the positive charge from the glass rod passes away along the cotton thread to the earth, and negative electricity passes up from the earth along the same path to take its place. This negative continues to be attracted by the positive on the charged rod, and that explains why one ball clings to the rod, while the other is repelled by it.

Summary of the Lesson

1. Water is a good conductor.
2. Damp air is a good conductor; dry air is a non-conductor.
3. Wood and cork are both conductors.
4. A pith-ball suspended by a dry silk thread is insulated, because dry silk is a non-conductor.
5. The same ball at the end of a cotton thread is not insulated, because cotton is a conductor.

Lesson LI

A Word about the Rubber

Before proceeding to the next step, let us review the position as far as we have gone.

To begin with then, we know that all bodies, before they are excited by rubbing, are in a neutral state; that is, they contain positive and negative electricity in equal quantities. The rubbing separates the two electricities, and the body is then said to be charged.

If it is charged with positive electricity, the negative disappears; if it is charged with negative electricity, the positive disappears.

That is to say, when we rub a glass rod with silk we charge it with positive electricity, and the negative seems to be lost; when we rub a rod of vulcanite, shellac, sealing-wax, or sulphur with fur or flannel, we charge it with negative electricity, and the positive seems lost.

In every case, you see, the opposite kind disappears. What becomes of it? That is the next puzzle for us to solve. Follow me carefully.

I have here a flannel cap, which is made to fit the end of the vulcanite rod, and has a silk cord attached to the top of it.

Let us for the moment imagine that the cap itself is charged with electricity. What would be the result if I held it up by the cord?

Of course you have no difficulty in telling that the cord would act as an insulator—it would prevent the electricity from passing away, because dry silk is a non-conductor.

Having settled that point, we will now present first the rod and then the cap to the suspended pith-ball, and watch the result.

You observe that neither of them affects the ball in any way—there is no attraction, no repulsion—and hence it is clear that both are neutral. That is to say, they contain positive and negative electricity in equal quantities.

Now, after warming both by the fire, I will place the cap well over the end of the rod, and one of you shall hold it by the silk cord, while another twists the rod itself round and round in it about ten or a dozen times.

The rubbing of the flannel cap on the vulcanite must, as you know, charge the rod with negative electricity. But if, without removing the cap, you bring the rod near the suspended pith-ball, you observe that there is still no movement whatever.

The rod, although we know it must be charged

with negative electricity, fails either to attract or repel the pith-ball. It still acts precisely like a neutral body. This is puzzling. Let us try to find out the meaning of it.

Pull the cap off the rod by the silk cord, and hold it near the pith-ball, and you see that the flannel cap itself attracts the ball, showing that it is now charged with electricity.

Then bring the rod near it in a similar way, and you observe that in this case again there is instant attraction. The neutral ball is attracted in turn first by the cap and then by the rod.

I need scarcely remind you that neutral bodies can be attracted only by charged bodies; and hence it is clear that both the cap and the rod are now charged with electricity.

We know then that the cap is charged, and that the charge cannot escape, because the suspending silk cord acts as an insulator.

Now, as the next step, I will charge the pith-ball itself positively by touching it with the electrified glass rod, and you shall once more approach it with the flannel cap, still suspended of course by the silk cord.

As you do so, you observe the repulsion which takes place. The ball flies away from the cap.

Now, we know that the pith-ball is charged positively, and that like charges repel. Hence it is evident that the cap itself must be charged with positive electricity.

We will, in the next place, bring the vulcanite rod near the pith-ball, and you observe that the ball instantly flies to the rod. There is violent attraction. Here again the whole result is very clear. The pith-

ball is charged positively, unlike charges attract, and therefore the rod which attracts the positively charged ball must itself be charged with negative electricity.

We conclude from these experiments that when vulcanite is rubbed with flannel, both kinds of electricity are generated, and that one kind cannot be produced without the other.

It is equally conclusive that the negative charge goes to the rod, and the positive charge to the rubber; and as the two charges neutralise each other while the cap remains on the rod, it is evident that they must be equal in quantity.

Now let us take another step. I will rub the vulcanite rod with the flannel in the usual way, and then lay the flannel on the cap of the electroscope.

We know that the rubber is charged as well as the rod. Is it not strange then that there is now no movement in the gold leaves? Here is another puzzle, which we must solve.

You know that when a charged body touches the cap of the electroscope, it shares its charge with the leaves, and the leaves by diverging show that they have received the charge. But in this case the leaves remain neutral, and it is therefore clear that they have received no charge.

The truth is, there is no charge whatever on the flannel now, although it took away all the positive electricity during the rubbing. What then has happened since? Let me show you.

I will repeat the experiment, but this time, before taking hold of the flannel, I will put on an india-rubber glove.

When the charging is over, you observe that the

leaves diverge immediately the flannel touches the cap, evidently proving that there is a charge on the flannel this time.

Then too, while the flannel rests on the cap, if I charge the glass rod with silk, and touch the cap with the charged end, you will see the leaves diverge still more, showing that the positive charge from the glass repels a like charge in the leaves, and of course that charge must have come from the flannel rubber.

If we repeat the experiments, substituting the glass rod and silk rubber for the vulcanite and flannel, we know that the charge given to the glass is positive, and that therefore the silk must be charged with negative.

But it is clearly seen that, when the rubber is held in the bare hand, the charge on it is lost; and when the insulating india-rubber glove is worn, the charge shows itself by making the leaves diverge.

You will now understand that in charging a body we separate the positive electricity from the negative, one charge remaining on the body rubbed, the other going to the rubber.

The puzzle of being unable to trace the charge on the rubber in the ordinary way has also been unravelled; for you know that as rapidly as it is developed it escapes by the hand, and so through the body to the earth.

The glove, being an insulator, prevents the escape of the charge from the rubber.

Summary of the Lesson

1. When a glass rod is charged with positive electricity, the negative charge goes to the rubber.

2. When vulcanite, sealing-wax, shellac, or sulphur is charged with negative electricity, the positive charge goes to the rubber.

3. When we charge a rod in the usual way the opposite charge disappears from the rubber.

4. It is conducted away by the hand which holds the rubber, and so it escapes through the body to the earth.

5. We can retain the charge on the rubber by insulating it with an india-rubber glove.

Lesson LII

Electric Induction

Our first introduction to the piece of amber, you remember, showed us how electric force can be

generated by friction. Then, after following this up by rubbing a variety of bodies with suitable rubbers, we took another step, and found that bodies may be charged by mere contact, without any rubbing at all.

Now let us take a third step.

I rub the vulcanite rod with fur or flannel, and bring it slowly and gradually near the cap of the electroscope without letting the two things touch.

As this is being done, and even while the rod is some distance off, you observe that the leaves begin to diverge; and as it approaches nearer, they spread farther and farther apart.

Of course I need not remind you that this divergence of the leaves proves that they are charged with electricity.

If I now withdraw the rod in the same slow, gradual manner, you observe that, as it moves away, the leaves begin to collapse, so that when it is quite removed they hang parallel once more—they are no longer charged.

Now watch again while I repeat the experiment with the rod more strongly charged, and you will observe that it affects the leaves at a greater distance now, making them at the same time diverge more than they did before.

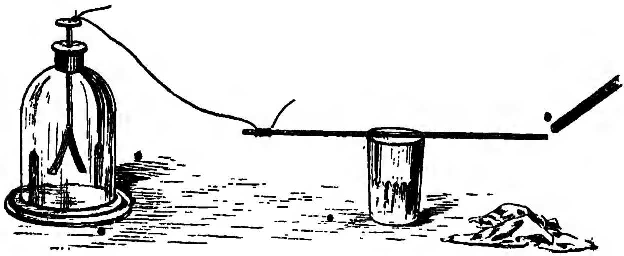
Two things must be carefully borne in mind during these experiments. The first is that the rod and the electroscope do not once come into contact; the second is that the dry air between the two is an insulator. Hence it is clear that the leaves could not have been charged by conduction.

It was the influence of the charged rod acting across the insulating air-space which charged the leaves. While they were under that influence the leaves repelled each other, because they were both charged with the same kind of electricity; but when the influence was removed the leaves became neutral again, and in that state they collapsed.

This charging by influence is called induction. The charged body which exerts the influence is known as the inducing body; the body which is acted upon is called the induced body; the charge given to it is said to be an induced charge; and the insulating air-space through which induction acts is called the di-electric.

Let us now endeavour to find out what actually takes place when a body is charged by induction.

I will insulate this metal bar by resting it on a glass tumbler, and then connect one end of it with the electroscope by means of a piece of copper wire,



attaching one extremity of the wire to the cap, and twisting the opposite extremity round the bar itself.

When the connection has been completed in this way, it is clear, not only that the bar, the wire, the cap, and the leaves, being made of metal, are all conductors, but also that, as they are all connected together, they practically form a single conductor.

If now I strongly charge the vulcanite rod once more, and bring it slowly near the far end of the metal bar, you will observe that the leaves of the electroscope at the opposite end at once diverge.

You know they cannot have been charged by conduction, for they are not connected in any way with

the excited body. Hence it is clear that the influence of the charged vulcanite rod is inducing electricity in the metal bar near it, and that the leaves of the electroscope diverge as a result of this induction.

But we must go farther than this. Lift the wire now with the non-conducting glass rod, so as to break the connection between the metal bar and the electroscope, while I still keep the inducing vulcanite rod in the same position. When that is done, you observe that the leaves still remain spread out—they are still charged with electricity.

Now watch what happens when I bring the vulcanite rod nearer. They diverge still more; that is to say, there is greater repulsion than before. Now we know that the charge on the vulcanite is negative; and we also know that like charges repel. Hence it is clear that the leaves themselves must have been charged with negative by induction.

But we also know that unlike charges attract, and that leads us to infer (and it can easily be proved) that the end of the metal bar nearest to the negatively-charged vulcanite is itself charged with positive electricity.

Indeed, we may sum up by saying that when a body is charged by induction its electricities are separated by the influence of the inducing body, which repels the like and attracts the unlike.

If, as we have seen, the inducing body is charged negatively, it will attract positive and repel negative to the leaves; but if the inducing body is charged positively, it will attract negative and repel positive to the leaves.

In this respect the induced body resembles a

magnet, for it has two poles, and we may say it is polarised.

If we substitute rods of glass, vulcanite, sealing-wax, and shellac for the metal bar, there is no evidence of induction, no polarisation in any of them, however strong the charge, and the reason for this is obvious. Glass, vulcanite, sealing-wax, and shellac are non-conductors; they resist the flow of electricity, and hence their electricities cannot be separated.

Induction can only take place with conductors.

Summary of the Lesson

1. Induction takes place when a charged body exerts an influence over another body without touching it.
2. The insulating air-space between the charged body and the body under induction is called the dielectric.
3. The induced body becomes polarised.
4. The charged, or inducing body repels the like, and attracts the unlike electricities of the body under induction.
5. Induction can only take place with conductors.
6. Non-conductors resist the flow of electricity. Hence polarisation cannot take place, and there can be no induction.

Lesson LIII

More about the Electroscope

Our recent lessons have shown us the use of the electroscope, and in the next place I want you to learn how to make one for yourselves. But before we proceed with this, suppose we have a little talk about the instrument itself.

Look at it as it stands on the table, and you see

that the leaves hang parallel side by side. But why do they hang parallel? Because they are neutral.

What does that mean? It means that they are in an uncharged state.

How could we charge them? By bringing a charged body near.

What would happen then? The electroscope would be charged by induction, and the leaves would diverge.

Why do they diverge? They repel each other, because both are then charged with the same kind of electricity, and like charges always repel.

Exactly; and from this we learn that the first use of the electroscope is to show the presence of electricity.

You remember also, no doubt, that in our last lesson we approached the electroscope first with a slightly charged rod, and afterwards with the same rod more vigorously rubbed. What happened?

The strongly charged rod affected the leaves at a greater distance, and made them diverge more than they did under the influence of the slighter charge.

Quite right; and it is clear from this that the next use of the electroscope is to show the amount of electricity with which a body is charged.

Those same experiments, too, proved that if a body charged with positive electricity causes the leaves of a charged electroscope to diverge more, the electroscope itself must be charged positively; and, on the other hand, if a body charged with negative electricity causes the leaves of a charged electroscope to diverge more, we know that the electroscope itself must be charged negatively.

Or we may put it in another way by saying that if an electroscope is charged with either kind of electricity, and a charged body causes its leaves to diverge more, we know that the body itself and the electroscope are similarly charged.

Hence, if we know how the electroscope is charged, we can at once tell the nature of the charge on the body we wish to test. Therefore, you see, a third use of the instrument is to determine the kind of electricity with which a body is charged.

Now, as we have all the materials ready to hand, I will at once proceed to make an electroscope, and I want you to pay particular attention, because I am going to offer a prize for the best one you can afterwards make for yourselves at home.

Let us commence with the most essential part of the contrivance—the gold-leaf. Look at this piece which I hold in my fingers. It is very delicate and flimsy; the least breath of air blows it about, you see. This at once gives us a reason why these leaves must be kept in a closed vessel. It prevents them from being blown about by the movement of the air.

But there is another reason. The air on damp foggy days is full of moisture, and damp air you know is a conductor, and would rob the leaves of their electricity.

The glass vessel, therefore, protects the leaves not only from the movement of the air, but also from damp. At the same time it is transparent, so that we can see the leaves distinctly. This bottle, with a cork to close it, will suit our purpose well.

Now, I have here a piece of copper-wire and a round disc of the same metal, and the next step is to

solder one end of the wire to the centre of this disc. When that is done, of course the disc and the wire will form a single conductor, along which electricity can flow to the inside of the bottle.

But the wire must pass through the cork, and as cork is a conductor, the electricity would pass away from the wire to the cork, and never reach the inside of the bottle.

What must be done to prevent this? The wire must be insulated.

How shall we do that? By surrounding it with some non-conducting material, so that it cannot come in contact with the cork.

Quite right; and this is what we must do next. I will bore a hole through the middle of the cork, and insert a piece of glass tubing in it. Then if we pass the wire through the tube, and fix all three firmly together with a patch of hot sealing-wax on the top of the cork, we shall know that the wire is safely insulated, for glass and sealing-wax are both non-conductors.

Now, as the next step, we will solder to the lower end of the wire this little piece of thin sheet-brass, to form a support for the gold-leaves; and when that is done, all that remains is to cut the two strips of gold-leaf and fix them where they are to hang.

This, however, from the nature of the gold-leaf itself, is the most delicate part of the whole business, for the thin flimsy material is very liable to be torn.

The best way is to fold the gold-leaf between a sheet of paper, and cut it with the scissors. Then, instead of trying to pick it up with the fingers, touch the two sides of the little brass plate with the smallest

drop of weak gum, and slightly press them one by one on the ends of the two strips of gold-leaf. In this way it will be easy to fix them without touching them with the fingers.

Nothing more remains to be done but to lower them into the bottle, and fit the cork securely in the neck, and our electroscope is complete.

Summary of the Lesson

1. The electroscope enables us to detect the presence of electricity.

2. It shows the quantity (more or less) of electricity with which a body is charged.

3. It determines the kind of electricity with which a body is charged.

4. A clean, dry transparent vessel is necessary, to exclude draughts and damp, and enable us to see the leaves.

5. Cap, rod, and leaves are all conductors.

6. The glass tubing and shellac-fixing insulate the wire from the cork.

Lesson LIV

The Electrophorus

As our next step, we must now endeavour to make ourselves familiar with another useful instrument, the electrophorus, for that will lead up naturally to a very interesting part of our subject.

Here is the instrument, and you see it consists of three distinct parts, which are known respectively as the sole, the plate, and the lid.

The plate is the most essential of these three parts, so we will deal with that first.

It is simply a round, flat, thin disc of vulcanite, and you know that vulcanite is a non-conducting material, which develops a charge of negative electricity, when it is rubbed with fur or flannel.

Take this vulcanite rod, and after exciting it in the usual way by rubbing it with fur or flannel, draw the charged end once or twice across the cap of the electroscope, as if in the act of wiping off something from it.

As that is being done, you observe that the leaves diverge, and you know, of course, that they repel each other because both are charged with the same kind of electricity.

But can you tell me how they were charged? They were charged by conduction, when the rod came in contact with the cap.

Exactly: the fact is, the negatively charged rod parted with some of its own charge to the leaves, and they therefore, like the rod itself, are now charged negatively.

Having settled this point then, we will now turn our attention to the vulcanite plate. Warm it by the fire, and then after rubbing it well with the warmed catskin, bring it cautiously near the cap of the electroscope.

When this is done, you observe that the already diverging leaves spread out still farther as the plate approaches.

You observe too that the charged plate acts on the leaves by induction, for it does not come into contact with the electroscope, and the further divergence of the negatively charged leaves is a proof that the plate is also charged negatively.

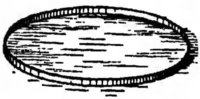
This plate is usually known as the generating plate, because in using the instrument we always commence by rubbing the plate itself with fur or flannel, to generate or develop a charge on it.


THE PLATE.

Now let us pass on to notice the round metal dish in which the vulcanite plate rests. It is known as the sole, and is intended to be the connecting link between the generating plate and the earth.

Hence it is always made of metal, or some other conducting material.

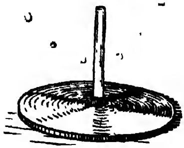
The third part of the contrivance is called the lid or cover. It consists essentially of a metal disc, which is slightly smaller than the vulcanite on which it rests, and is provided with an upright glass handle fixed to its centre.


THE SOLE.

The metal disc itself, which rests on the generating plate, is a conductor; the glass handle is a non-conductor.

If therefore the disc receives a charge, the electricity cannot pass away, because the glass handle acts as an insulator, and obstructs its flow.

There is one point in connection with the lid and the generating plate to which I must now specially direct your attention, because it would escape your notice otherwise; and as it is a most important part of the whole contrivance, you must be careful to bear it in mind, for we must refer to it later on.


THE LID.

You observe that although the lid rests on the plate, I can easily pass this slip of paper between the two, and that is sufficient to prove that they do not touch at all points, or in other words that there is some amount of space between them.

This space of course is filled with air, and so it follows that the generating plate is separated by this thin layer of air from the conducting metal disc above it.

We shall have more to say about this; but for the present it will be sufficient for you to clearly understand the use of each part of the contrivance.

The vulcanite plate is for the purpose of generating or developing a charge of electricity; the metal sole is to act as a conductor between the plate and the earth; and the glass handle, being an insulator, is to prevent the electricity on the lid from passing away when we take hold of it.

Summary of the Lesson

1. The vulcanite disc of an electrophorus is known as the generating plate.

2. The original charge is given by rubbing this plate with fur.

3. The metal sole, being a conductor, is intended as the connecting link between the generating plate and the earth.

4. The lid, or cover, consists of a metal disc with an insulating handle.

Lesson LV

The Electrophorus at Work

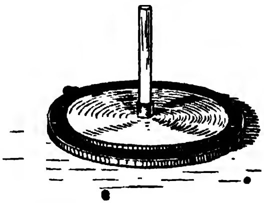
In our last lesson we examined the different parts of the electrophorus; our next business will be to learn how it is used.

We will commence at once then by holding the generating plate in front of the fire, to thoroughly dry and warm it, after which we will place it in the sole, and rub it vigorously with the warmed catskin.

The rubbing, of course, develops negative electricity on the upper surface of the disc. But you must remember that vulcanite itself is a non-conducting material, and that the sole in its present state is neutral, and in connection with the earth.

Under these conditions the non-conducting vulcanite becomes the dielectric. The negative charge on the upper surface of the plate acts by induction through this dielectric vulcanite, attracting positive electricity to the top of the sole, and holding it bound there, while it repels negative electricity from the sole to the earth.

I now take the lid by the insulating glass handle, and place it on the charged vulcanite plate. But before doing so we must remember that, like the sole, it is in a neutral state, for it has not been excited or charged.

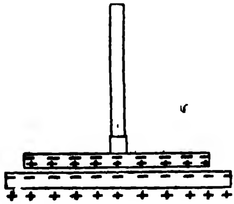


Let me also remind you that the two discs have been purposely made so as to touch at only a few points, and that consequently there is a thin layer of air between them.

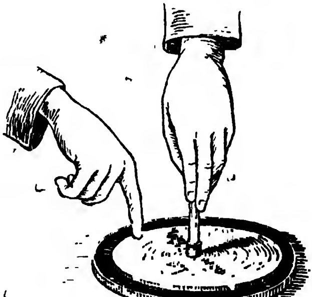
This thin layer of air then becomes the dielectric between the plate and the metal disc above it, and the plate acts on the disc through this dielectric by induction, so that the electricities of the neutral lid are separated or polarised.

The positive is attracted to the under surface of the lid by the negative charge on the vulcanite plate; and the negative is repelled to the upper surface of the lid.

Now observe that, as the next step, I touch the top of the lid with my finger, and the result is that the repelled negative on the top of the lid escapes through my body to the earth.



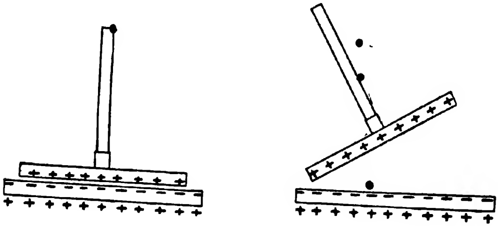
But what becomes of the positive on the under surface of the lid? That, you remember, cannot escape, for it is held bound by the negative charge on the plate.



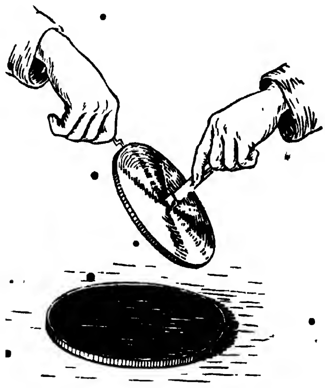
I will now remove my finger, and afterwards raise the lid from the plate by the insulating handle; and when that has been done it is clear that the positive charge on the lid is no longer under the inducing influence of the generating plate.

But although free from that influence, it cannot

escape, because the glass handle insulates it, and hence it spreads itself all over the surface of the lid.



Therefore, if all this is correct, we should expect to find that the lid is now charged with positive



electricity. Let us see whether this is actually the case.

Bring your knuckle near the edge of the lid, as I still hold it by the handle.

Ah! I thought it would give you a start. You did not expect that spark and that crackling snap.

Now let me explain. The charged lid, as I held it, was in an unnatural state, and the balance had to be restored. When a neutral body, such as your hand, approached, a rapid exchange took place.

The lid parted with some of its positive charge to your hand, and at the same time took away negative from it. This exchange is Nature's way of making the lid neutral again, and was the cause of the spark and sudden snap.

Summary of the Lesson

1. The electrophorus acts by induction.
2. The non-conducting vulcanite is the dielectric between the negative charge on its upper surface and the sole on which it rests.
3. The negative charge on the plate polarises the sole, holding its positive electricity bound, and repelling its negative to the earth.
4. Induction also takes place between the plate and the lid.
5. Positive is attracted to the under surface of the lid, and negative is repelled to the top.
6. When the finger touches the top of the lid, the repelled negative is conducted away, but the positive is held bound.
7. When the lid is lifted out of range of the inducing influence of the plate it is found to be charged with positive electricity.

Lesson LVI

Electricity in the Air

Our recent experiments with the electrophorus were intended as a stepping-stone towards the proper

understanding of one of the most wonderful of Nature's phenomena.

In those simple experiments, it is true, we could not do more than produce a spark and a snap; but with suitable apparatus it is an easy matter to obtain larger and much more brilliant flashes, accompanied by loud explosive cracks.

It was the sudden flash of the electric spark produced by these experiments, and the explosive cracking noise accompanying it, which first led men to guess at the real nature of lightning as a flash of electricity through the air.

This guess naturally led to the inquiry as to where the electricity came from, and the question was solved by Franklin in a curious way.

He let a kite up into the air by means of pack thread, having first fitted to it a steel wire, the top of which stood an inch or so above the kite itself. To the lower end of the thread he fastened an ordinary door-key, and to the key he tied a silk thread for holding it, so as to insulate it from the hand.

Then, after connecting the key with the cap of an electroscope, he waited for the result. The electroscope showed no sign at first, but after a time rain began to fall, and almost immediately the leaves diverged, showing that they had received a charge.

The explanation, of course, was simple. The electricity was in the clouds, and the steel wire, being a conductor, collected some of it, and passed it on to the thread which held the kite. The wet thread, being also a conductor, carried the charge down to the steel key, and so to the electroscope.

In this way, you see, Franklin actually brought

electricity down from the clouds, and since his time similar experiments have proved that electricity is always present in the atmosphere, but in varying quantities. In fine weather the clouds are usually charged with positive, but during rain, hail, or snow negative mostly prevails.

And now I suppose you are beginning to wonder where this electricity comes from, and why it is always present in the air. Let me explain.

In the first place you must remember that the air is one of Nature's great agents, and that it is never still—it is always on the move.

The heated, rarefied air, forced upwards and onwards by the colder and denser air all round, becomes a wind; and water vapour, constantly rising, not only from the vast bodies of water, but from the solid earth itself, and from all animals and plants, is also a source of movement.

The whole atmosphere, you know, is made up of minute particles of air and water-vapour, and it is the mass of these particles which are constantly on the move.

But like every other kind of matter, they must produce some amount of friction, as they brush by one another, and friction, as you know, produces electricity.

These simple natural movements of the air are then the sole explanation of the wonderful phenomena of lightning and thunder.

The moving particles of air and water-vapour produce friction; the friction produces electricity; every little particle of water-vapour is itself a conductor; and the electricity produced in this way

is carried upwards by these particles of water-vapour, as they rise to form the clouds.

Hence it is that the clouds themselves become Nature's great storehouse of electricity.

Now let us imagine a positively-charged cloud to be hovering over some particular place, and I think, from what you already know, you will be easily able to explain everything that follows.

In the first place, let me point out that between the cloud and the earth is the dry insulating air, and that of course becomes the dielectric. Under these conditions, you remember, the positively-charged cloud can act on the earth only by induction, attracting negative and repelling positive electricity.

Hence that part of the earth directly under the cloud, and everything on it—trees, buildings, and living creatures—are all charged negatively, and we can easily deduce the rest.

We know, to begin with, that every charged body struggles to become neutral again as soon as possible. You remember that all the time the lid of the electrophorus was charged, there was a struggle going on with this very object, and of course the opposing or resisting body was the dielectric air all round.

When you brought your knuckle near, there was only a small space of this opposing air between it and the lid, and the inductive force of the charged lid overcame the resistance of the air, so that an exchange took place.

The positively-charged lid gave up some of its positive to the hand, and robbed the hand of some of its negative; and this exchange of electricities was made evident by the spark and the sharp snap which accompanied it.

Apply this to the charged cloud, and the whole phenomena of lightning and thunder are as clear as noon-day.

As the cloud sails along, it gets so near the earth that its inductive force overcomes the resistance of the dielectric air; and the moment this happens an exchange takes place, the cloud giving up to the earth some of its positive, and receiving from the earth some of its negative, or *vice versa*.

The passage of this electric discharge from the cloud is made evident by the brilliant flash, which we call lightning, and the loud noise resembling an explosion, which is known as thunder.

Summary of the Lesson

1. Electricity is always present in the atmosphere.
2. The clouds are Nature's great storehouse of electricity.
3. In fine weather positive electricity abounds, but in damp rainy weather negative is usually prevalent.
4. Evaporation and the winds are Nature's generators of electricity.
5. A charged cloud acts on the earth by induction; the air between the two is the dielectric.
6. The inducing cloud polarises the earth below it, repelling its like, and holding bound its unlike electricity.
7. When the distance between the cloud and the earth is such as to enable the attractive force of the two electricities to overcome the resistance of the dielectric air, there is a flash of lightning, caused by the exchange of electricities which takes place.

Lesson LVII

Lightning and Thunder

In our experiment with the electrophorus we saw the electric spark, and our last lesson showed us that

every flash of lightning is really an electric spark on an immense scale—Nature's electric spark.

Let us now proceed to investigate the cause of the report.

In the first place, then, it is easy to understand that, when the discharge takes place the lightning heats the air in its passage, and of course this heating causes a sudden expansion.

This expansion is followed naturally by an equally sudden rush of air into the rarefied space; and the expansion and consequent rush of the air itself are supposed to be the cause of the violent report, which always accompanies a lightning flash.

You know that the same thing happens when a gun is fired, for there is first a flash and then a report.

If a person stands near the gun when it is fired, he sees the flash and hears the report at the same instant; but if he watches it from a distance, the report is not heard till some time after the flash is seen.

In the same way lightning and thunder actually occur at the same instant; but light travels, as you know, at the rate of 185,000 miles a second—it is in fact instantaneous—while sound travels only about 1200 feet a second.

Hence it is an easy matter to calculate the distance of the spot where the discharge takes place, if we multiply 1200 feet by the number of seconds which intervene between the flash and the report.

Thus, if we hear the thunder six seconds after seeing the flash, we know that the discharge has taken place 6×1200 feet from the spot where we stand.

Now as regards the lightning itself, every one knows that it is not always the same in character. One kind is commonly described as forked lightning, another as sheet lightning.

Forked lightning takes a sort of zig-zag path to the earth, and this is probably due to the unequal pressure of the air through which the discharge passes, the flash taking the path of least resistance.

Every electric discharge, however, as it rushes through the air in its zig-zag path, illumines the cloud from which it emanates, and is reflected in distant parts of the heavens, and it is this reflected flash of a distant discharge which we call sheet lightning. It lights up the whole sky.

It frequently occurs too that flashes of sheet lightning are seen to illumine the whole horizon, but at so great a distance that the thunder cannot be heard. This is known as heat lightning, or summer lightning.

The rarest and most dangerous of all Nature's discharges is the one known as globular lightning. This is so called because, when a discharge takes place, globes or balls of fire are seen to move somewhat slowly towards the earth, and then suddenly explode with fearful violence.

Now a word or two more about the report which follows the lightning flash.

From your own experience you know that, at one time there is a single report, like a sudden violent explosion; at another the thunder seems to burst into a rapid succession of discharges resembling the rattle of quick-firing guns; and at another again it rolls through the air with a noise like the rumbling of heavy waggons.

The first, which is known as a thunder clap, always accompanies a discharge which travels by a short direct path. The rattling thunder is produced when the discharge moves in a zig-zag path, and the rolling or rumbling thunder is simply the echo, or reverberation of the discharge through the clouds.

Summary of the Lesson

1. Lightning and thunder may be regarded as Nature's electric spark.
2. Forked, sheet, and globular lightning are varying forms of Nature's display.
3. The report or discharge also takes varying forms, such as the thunder clap, the thunder rattle, and rolling or rumbling thunder.

Lesson LVIII

The Lightning Conductor

Few people, I suppose, ever contemplate a thunderstorm without some amount of dread, more or less, because of its dangerous character.

When the discharge takes place, it strikes everything in its path, killing men and animals, firing and destroying buildings, blasting trees, and even melting metals.

Let me once again explain the nature of the phenomenon.

A cloud charged with one kind of electricity induces the opposite charge in the earth below it, and of course it attracts the induced charge to the nearest possible point.

These two charges are only kept apart by the resistance of the dielectric air between them, and if the cloud approaches near enough for its electricity to overcome that resistance there is an instant discharge.

Now it is clear that, as the tops of buildings and trees offer the nearest and most direct path from the cloud to the earth, they are the most likely objects for the electric discharge to strike.

If the lightning strikes a tree the discharge finds an easy path to the earth, because wood is a good conductor of electricity.

But it sometimes happens that cattle, and even thoughtless ignorant people, take shelter under a tree during a thunder-storm and are killed.

The reason of this is that the bodies of men and animals are even better conductors than wood, and the discharge after striking the tree leaves it at once for these living bodies, because they afford an easier path to the earth.

One of the first things a child should be taught is that, it is highly dangerous to take shelter under a tree during a thunder-storm.

Let us now imagine a man out in the open, with a heavy thunder cloud stretching for miles across the sky overhead, and for the sake of example we will suppose that it is charged positively.

Under these conditions it is clear that the man's body, like the ground and everything around him, will be negative by induction, and that all the positive electricity will be repelled to the earth.

Now suppose that, while things are in this state, there is a discharge from the cloud some distance off. The discharge of positive electricity from any one

point tends to neutralise the whole cloud, and the result is that induction ceases for a moment, leaving the repelled positive free once more to return to the surface of the earth.

There is, in consequence, a sudden upward rush of positive electricity from the earth to neutralise everything on its surface, and the man receives a violent shock, which is commonly known as the return shock, and often proves fatal.

But let us suppose that the man has a pair of strong india-rubber or gutta-percha-soled boots on his feet, and note the difference.

Induction takes place of course in the usual way; the charged cloud attracts the unlike and repels the like electricity. But the repelled electricity cannot escape from the man's body to the earth, because the non-conducting soles of his boots insulate him.

If therefore the cloud is charged positively, his body is polarised, the upper part of it being negative, the lower part positive; and when the discharge takes place and induction suddenly ceases, he feels a slight shock, but it is only caused by the mingling of his own electricities, and not by any violent rush of positive from the earth.

The dangerous character of lightning led men to devise some means of protecting their buildings on land and their ships at sea from its effects; and the best protection was found to be a long metal rod, fixed to the side of the building or the mast of the ship.

All metals you see are good conductors, and offer an easier path for the passage of electricity than that afforded by other bodies.

The rod, in fact, attracts to itself the lightning

which would otherwise have struck the building or the ship; and the charge thus attracted to the metal rod is conducted by it down to the ground, or into the water, as the case may be, without being allowed to come into contact with the objects that are to be protected.

Hence these rods of metal came to be called lightning conductors, but after all the name only conveys half the truth.

It is quite true that the metal rod affords a downward passage for the electric discharge from the clouds; but at the same time it provides an equally easy upward path for the opposite and induced charge from the earth.

Wherever you see a lightning conductor, you will observe that the top of the rod is carried some little distance above the highest point of the object to be protected, and the reason for this is obvious, for the induced electricity is always attracted to the highest possible point above the earth's surface.

But perhaps you want to know what is gained by making it easy for the induced electricity to escape from the earth to the clouds. I will explain.

The cloud, at every discharge, is being rapidly and constantly robbed of its electricity; and the constant upward stream of the opposite kind from the earth tends to further neutralise what is left, and so render it harmless.

Now that you are clear as to the purpose of the lightning conductor, it will be well to notice a few points of detail in connection with it.

In the first place the rod itself is usually made of galvanised iron or copper, and it must be continuous from bottom to top, without a flaw or break of any kind.

It must be connected in some way with all the outside metal work of the building such as gutters, pipes, and spouts, and the top of it must terminate in a fine point, because electricity always passes off more rapidly from points than from blunted or rounded ends. The lower end of it—the earth connection as it is called—should terminate either in a well of water, or in the soft damp earth, so that the conducted downward charge may spread in all directions, and thus become harmless.

SUMMARY OF THE LESSON

1. The tops of trees and tall buildings are the most likely objects to be struck, because they are nearer than the surrounding objects to the overhanging cloud.

2. The lightning in its path to the earth leaves the tree for a living body, because, although wood is a good conductor, the bodies of men and animals are better conductors.

3. The return shock is caused by the sudden upward rush of the repelled electricity from the earth to neutralise everything on its surface the moment the inducing influence of the cloud ceases.

4. The lightning conductor affords a ready downward path for the electricity from the cloud, and an equally ready upward path for the earth's induced electricity.

5. The induced electricity, which flows off in a constant stream from the top of the lightning conductor, tends to neutralise the charged cloud.

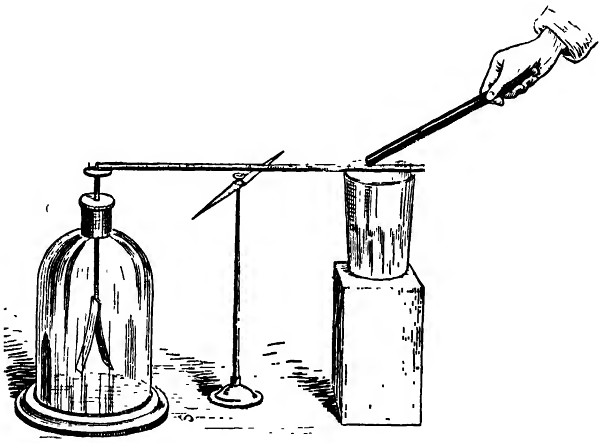
Lesson LIX

CURRENT ELECTRICITY

We are now about to take another step in electricity, and we will commence by referring to one of our former experiments.

I rest one end of a metal rod on a glass tumbler, and the other end on the cap of the electroscope. Then if I stroke the end resting on the tumbler with a strongly charged vulcanite rod, what will happen? The leaves will diverge, showing that they are charged with electricity.

Quite right; but I must remind you that the charge is given at one end and the leaves are at



the other. What is therefore the only inference? The charge must travel along the rod.

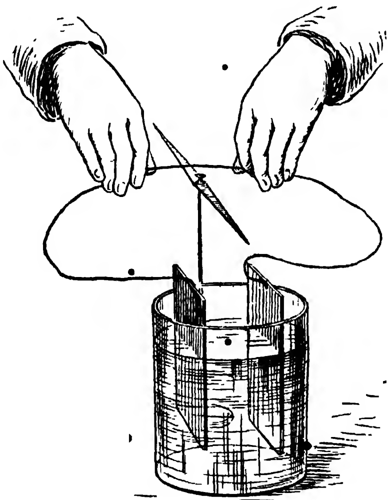
Right again; and that is the reason why we call the metal rod a conductor, and say that electricity flows along conductors.

We will now make this experiment our starting-point, but this time I will place the magnetic needle just below the metal bar, so that the two are parallel, but do not touch.

If we now stroke the bar with the charged vulcanite

rod as before, we observe that not only do the leaves diverge, but the needle becomes agitated and moves on its pivot. The magnetic needle therefore affords another evidence of the flow of electricity.

Now for our new and strange step. I have here some dilute sulphuric acid, which I will pour into this glass jar, filling it about three parts full. Then I will



stand in the acid these two strips of metal, one copper, the other zinc.

You observe that the two metals are connected at the top by means of copper wire, but I shall be careful not to allow them to come into contact in the acid itself.

Now I will take this connecting wire in my hands, and hold it in a line over the magnetic needle, and you observe that the needle at once begins to turn on its pivot as before.

If you compare this with what you have just seen, you must come to the conclusion that the movement of the needle is a proof that electricity is flowing along the wire. But how did it get there? Let us try to answer this question step by step.

You noticed that the acid began to bubble, as soon as the metals were placed in it; and if you look closely you will see that the bubbles rise to the surface in thick clusters round the copper plate, while there are very few near the zinc plate.

If I remove the copper plate, and substitute for it a similar strip of iron, connecting the iron and the zinc with wire as before, you observe that the needle moves in exactly the same way, showing that there is a steady flow of electricity along the wire, and you see the same bubbling in the liquid as before.

But if I try the effect of using two strips of zinc, then two similar strips of copper, and lastly two strips of iron, there will be no movement in the needle; and although bubbling goes on round the pair of zinc plates, there are no bubbles at all when two copper or two iron plates are used alone.

When, however, we replace the wire-connected zinc and copper plates in the liquid, the commotion immediately starts again, and the needle shows clear evidence of a flow once more.

The natural inference of course is that there can be no flow of electricity with similar metals, but when two dissimilar metals are placed in the acid, a flow of electricity is started.

Suppose we now remove the wire connection, and test again as before. The needle gives no sign of movement. But if I make the two plates lean against

each other, so that they are in direct contact outside the liquid, there is evidence of a flow once more.

It is clear from this that the metals, besides being dissimilar, must be connected. But if we connect them with string, the needle again refuses to make any movement, for dry string is a non-conductor and obstructs the flow of electricity. Hence we infer that the metal plates must be connected by a conductor.

Now let us turn to the acid. You remember that the copper plate, when placed in the acid alone, produces no bubbles, while bubbles come from each zinc plate under the same conditions.

It is evident therefore that the bubbles, which are constantly rising in clusters to the surface near the copper plate, cannot actually come from the copper. They must have come from the zinc, and they must have been forced, or driven through the liquid itself in some way, from the zinc to the copper plate.

The constant output of fresh bubbles at the surface of the zinc plate becomes the actual force, which drives forward those in front, and they flow through the liquid in a stream or current, till they strike against the copper plate.

The force thus set up is not lost; it communicates itself to the copper plate. But that plate, the wire, and the zinc at its opposite extremity, are all conductors; and they conduct or carry back again the the force which was set up in the acid on the surface of the zinc plate.

The flow in fact travels round and round, from the

zinc through the liquid to the copper, and from the copper, along the connecting wire, back to the zinc again.

Hence electrical force produced in this way is known as current electricity.

Summary of the Lesson

1. The deflection of the magnetic needle proves that electricity is flowing along the conducting wire.

2. Sulphuric acid acts upon zinc, but not upon copper or iron.

3. There can be no flow of electricity with similar metals.

4. The metal plates must be connected by a conductor.

5. The bubbles come from the zinc, and are forced through the liquid to the copper.

6. The force of this stream, or current, is communicated to the copper, and conducted by the wire back to the zinc.

7. This flow of electric force is known as current electricity.

Lesson LX

Chemical Electricity

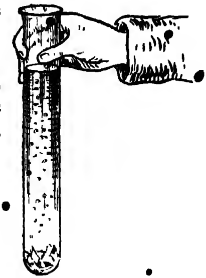
You remember, of course, that in our recent experiment the sulphuric acid, although it had no effect whatever on the copper plate, acted on the zinc, and caused a constant commotion or bubbling in the liquid.

Our next step must be to learn the nature of these bubbles, and for that purpose you shall hold this test-tube in your hand, while I first drop into it some of these zinc clippings, and then fill it about three parts full of the cool dilute acid.

You observe that bubbles at once begin to rise

upwards in a stream through the liquid. But what is the matter? Warm, is it?

So it is—in fact it is getting too hot to hold, so stand it in the rack, and we will see what it all means.



But perhaps you can tell me something about it yourselves, for we have seen the same sort of thing in former lessons.

What do you say? Chemical action is going on in the tube? Well, you are quite right. Chemical action *is* going on, and that is the cause of the heat, and also of the bubbles.

Look; I apply a lighted match now to the mouth of the test-tube, and something bursts into a blue flame. What do you think that something is?

Yes, you are quite right: hydrogen gas is burning there. Those bubbles which you see streaming upward through the liquid are bubbles of hydrogen.

The zinc and sulphuric acid are entering into new combinations, and during the process hydrogen gas is being evolved in bubbles, which rise up through the liquid, and burst on the surface.

Now suppose we leave the bubbles and the heat for the present, and turn our attention to the contents of the tube.

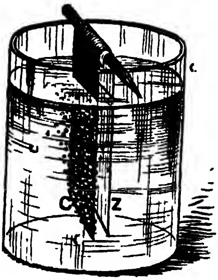
The first thing to strike one is that there has been a wasting of the zinc, and if we leave the test-tube where it is, we shall find after a time that it has all disappeared.

Then if we take some of the liquid, and heat it in an evaporating dish over the Bunsen burner, there will

be a residue—a white solid substance—left in the dish after evaporation.

This substance—sulphate of zinc—is a chemical combination of the zinc itself and what is left of the sulphuric acid, after its hydrogen has passed away in bubbles.

I have here now a small glass jar of the acid, with strips of zinc and copper foil suspended in it from a lead pencil.



You observe that the liquid is still on the bubble; hence we know that chemical action is still going on. The copper foil is thickly strewn with bubbles of hydrogen, and if we lift the zinc out of the acid, we see that it shows unmistakeable signs of waste.

Sulphate of zinc is being formed, and hydrogen gas is being set free in bubbles, which flow in a stream or current to the copper.

Let me now explain that sulphuric acid is a compound formed of the elements—hydrogen, sulphur, and oxygen. It consists of two parts hydrogen, one part sulphur, and four parts oxygen, and for this reason the chemist writes it shortly thus—H_2SO_4.

If you call to mind our lessons on Chemical Affinity, you will at once conclude that the reason why these particular elements combine in this particular way to form this particular compound, is because they have a particular attraction for each other.

The only way to break up this compound into its component parts is by bringing it into contact with

some other body, which has greater attraction or affinity for one of them.

Let me give you an illustration. Two boys A and B are playing together, when they are joined by a third boy C. Between this one and A there is a strong mutual aversion, although there is an equally strong affection between him and B. The mutual aversion drives A away, and then C and B commence a new game on their own account.

Something like this happens when zinc is brought into contact with sulphuric acid. Zinc has a strong aversion for hydrogen. It breaks up the combination by driving away the hydrogen of the acid.

The remainder of the sulphuric acid (which we may call the SO_4 group) cannot exist alone, and so it immediately combines with the zinc to form a new compound, sulphate of zinc.

The fact is, the affinity between the SO_4 and zinc is greater than that between the SO_4 and hydrogen. Hence it breaks with its original combination to form a new one.

Now let us follow this up, and see what actually takes place in the jar when the wire-connected plates are stood in the acid.

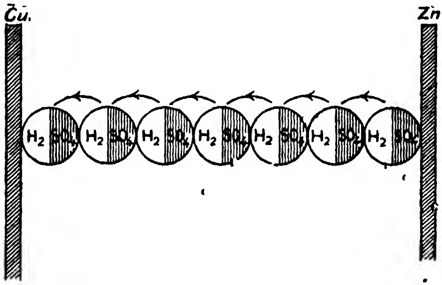
It is quite clear that there must be a layer of the acid in immediate contact with the surface of the zinc plate, and the result of the contact is to break up every molecule of that layer into two groups—H_2 and SO_4. The zinc and the SO_4 combine to form sulphate of zinc, and the hydrogen is set free.

Now it is a curious fact that this newly liberated hydrogen is very active in its properties. It is able to break up the combination in the next layer of

molecules, seizing the SO_4 to make a new molecule of sulphuric acid, and setting its hydrogen free.

You have only to picture to yourselves this same decomposition and recomposition going on through the next layer of molecules, the next and the next, until the layer nearest the copper plate is reached, and the whole thing will be quite clear.

This breaking up of the last layer of molecules sets their hydrogen free; but hydrogen has no affinity for copper, and therefore cannot enter into chemical combination with it. Hence some of it rises up the sides



of the plate in bubbles, which burst on the surface of the liquid, and the rest collects on the plate itself.

It is clear then that the chemical action between the zinc and the sulphuric acid not only liberates the hydrogen, but sets up a flow or current through the liquid from the zinc to the copper.

Under these conditions, and when the two plates are connected by a conducting wire, it is always found that the current set up in the liquid is conveyed to the wire itself, which thus acquires electrical force.

We say that a current of electricity is passing along

the wire, and hence it is that electrical force produced in this way is sometimes called chemical electricity.

Summary of the Lesson.

1. When sulphuric acid acts upon zinc, hydrogen gas is given off.
2. The residue is a new substance—sulphate of zinc.
3. The bubbles which flow through the acid from the zinc to the copper consist of hydrogen gas.
4. Sulphuric acid consists of hydrogen, sulphur, and oxygen: it may be written thus—H_2SO_4.
5. Zinc has a strong affinity for the SO_4 group, and an aversion for hydrogen.
6. The SO_4 cannot exist alone: it enters into combination with the zinc as soon as it is set free.
7. Decomposition and recomposition go on through the acid, molecule by molecule.
8. Some of the liberated hydrogen gas collects on the copper.
9. The rest rises in bubbles which burst on the surface.
10. The electrical force produced in this way is sometimes called chemical electricity.

Lesson LXI

Voltaic Electricity

Here is our glass jar, with the zinc and copper plates and the wire connection between the two, just as we used them in the last lesson. But before we pour in the acid, to set the current working, I want you to learn to call things by their proper names.

To begin with then, a vessel of any kind, fitted up in this way for electrical purposes, is called a cell.

There are several kinds of cells, but this one is the simplest of all in construction and working, and hence it is commonly called a simple cell.

It is also known as a voltaic cell, from the name of the Italian scientist, Volta, who invented it, and the electricity produced by its action is frequently called voltaic electricity.

Now let us watch the working of this cell a little more closely than we have done hitherto.

You observe that, as soon as the acid is poured in, the bubbling begins at the zinc plate; but you see at the same time other bubbles rising in a stream to the surface of the liquid near the copper plate, although you know that the acid has no effect whatever on copper.

Ah! I see that you are eager to explain that the action begins at the zinc plate, and that the bubbles of hydrogen are forced through the liquid from the zinc to the copper.

That is perfectly correct, and it explains why the zinc, which is the chemically active metal, is known as the positive or generating plate, while the copper, which is chemically passive, is called the negative plate.

Let us pass on, as the next step, to test the connecting wire with the magnetic needle in the usual way, and when this is done it at once becomes evident that a current of electricity is flowing along it.

You have already explained that a current is set up at the zinc plate, in the form of a stream of bubbles flowing through the liquid. But you must clearly understand that this stream of bubbles is not a current of electricity.

The real electric current first shows itself at the point of contact between the copper plate and the wire, and in consequence of this that point is known as the positive pole. The current thus started flows along the wire to the zinc plate, and the point where the wire joins that plate is called the negative pole.

The zinc is the positive (or active) plate for the chemical action in the cell, but its point of contact with the wire which conducts the current back is the negative pole.

The copper, on the other hand, is the negative (or passive) plate, as regards the chemical action in the cell, but its point of contact with the wire—the starting-point of the electric current—is the positive pole.

These simple voltaic cells were soon found to have several defects, and you have only to glance at a zinc plate, which has been in use, to discover one of these defects for yourselves.

The plate will be sure to show evident signs of the wasting action of the acid on it, and if it has been much used it will probably be eaten away in holes.

This useless waste of the zinc, however, can be prevented by coating the plate with mercury. It is first washed clean with dilute sulphuric acid, and then the mercury is spread evenly over its surface with a piece of linen.

The mercury unites with the zinc, and covers its surface with a silvery-looking amalgam of the two metals. This coating arrests the too rapid waste of of the plate, and we say the zinc is amalgamated.

There is another and even more serious defect, however, which gave considerable trouble at first. We will deal with that next.

Our cell has been at work all the time we have been talking. Let us test the wire with the magnetic needle as before, and you observe that the current seems to be very feeble now. It causes very little deflection in the needle. What can be the matter?

Look at the surface of the copper plate, and you will see that it is covered with bubbles. These of course are bubbles of hydrogen, and they adhere to the plate, forming a film all over it.

Now you remember that all gases are bad conductors. Hence the meaning of this obstruction is that, this film of hydrogen gas forms an insulating coat all over the surface of the copper, and opposes the flow of the current.

Let me prove this to you. I simply lift the copper plate out of the liquid and replace it again, and then the magnetic needle will prove that the current is as strong as ever.

The very act of lifting the copper plate out of the acid removes the hydrogen bubbles from it for the time being; and when it is replaced, the current is renewed, because there is no film of hydrogen to obstruct its flow.

But in a very short time the bubbles will accumulate on the surface again, and the current will become weakened as before.

It is clear from this that, in order to get a continuous unbroken current, the hydrogen must be constantly removed from the copper plate. But it is equally clear that the attempt to do this by lifting the plate out of the acid from time to time would in itself break the current.

This was the problem which had to be solved before

the voltaic cell could be of any real use, and in our next lesson we shall learn how the difficulty was overcome.

Summary of the Lesson

. vessel in which two dissimilar metals are placed in a
or the purpose of generating electric force is called a cell.

lectricity produced in this way is known as voltaic electricity.

3. The cell itself is usually called a simple voltaic cell.

4. In a cell the zinc is the positive, the copper the negative plate.

5. The point of contact between the copper plate and the wire is the positive pole.

6. The point of contact between the zinc plate and the wire is the negative pole.

7. The zinc plate is amalgamated to prevent the too rapid waste of the metal.

Lesson LXII

Cells and Batteries

I promised to explain to you how the accumulation of those hydrogen bubbles on the negative plate is prevented. Let me do so now.

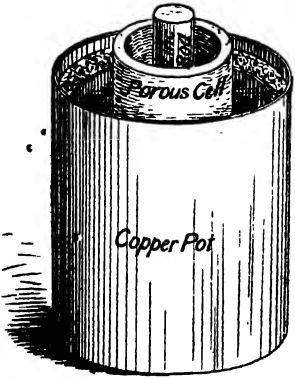
I have here another kind of cell, altogether different from the simple cell, with which you are already familiar. It is known as the Daniell cell, and consists, as you see, of two distinct cells, one within the other.

The outer one is a round copper pot or can, with a little shelf near the top. The inner one is a porous pot of unglazed earthenware, and in this porous pot stands a rod of amalgamated zinc.

You must remember that in this contrivance, the zinc rod is the positive plate, and the copper pot itself the negative plate.

I fill the inner porous cell with cool dilute sulphuric acid, which is thus in contact with the zinc rod standing in the midst of it.

I then place some of these crystals of bluestone on the little shelf in the outer cell, and fill up the cell itself with a strong solution of the same crystals.



By the by, the chemical name for these crystals is copper sulphate. They consist of copper, sulphur, and oxygen, and the chemist writes them shortly $CuSO_4$.

Well now, we have our cell prepared with positive and negative plates and two distinct fluids, and yet there is no action—no current. What remains to be done?

Yes, you are right; we must connect the two plates with a conducting wire. Therefore, with the help of binding screws, I will fit one end of this copper wire to the zinc rod, and the other end to the edge of the copper pot. Then if we test with the magnetic needle, we get clear evidence that an electric current is flowing along the wire.

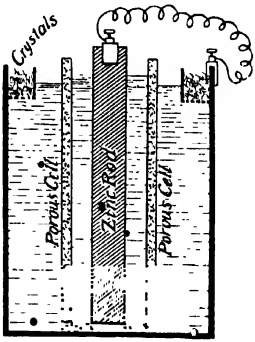
But we will leave the current for the present, and endeavour to find out what is going on in the cell itself.

Chemical action commences, of course, at the zinc rod in the inner cell, where as usual the zinc is acted

upon by the sulphuric acid, zinc sulphate is formed, and hydrogen is set free.

The usual decomposition and recomposition of the molecules of sulphuric acid go on through the liquid, till at last the liberated hydrogen reaches the wall of the porous cell, where it comes into contact with the copper sulphate ($CuSO_4$).

You remember that the newly liberated hydrogen is very active in its properties, and in consequence of this it breaks up the copper sulphate, turning out the



copper, and uniting with the other group of the sulphate (SO_4) to form sulphuric acid (H_2SO_4), which returns to the inner cell.

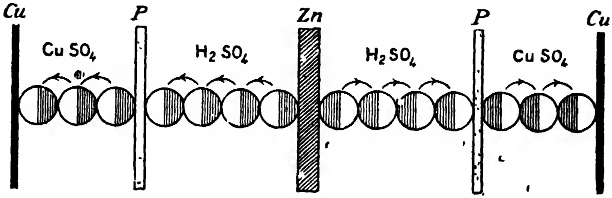
In this way the hydrogen disappears as soon as it is liberated, so that it never reaches the copper plate, and at the same time the acid in the inner cell is kept at a constant strength.

Each molecule of copper which is turned out by the hydrogen combines with the SO_4 of the nearest molecule of copper sulphate, and so decomposition and

recomposition go on in the outer cell, as well as in the inner one, the copper being at last deposited on the copper wall of the outer cell, where it can do no harm.

It now only remains to explain the purpose of those crystals of copper sulphate on the shelf. It is very clear that, all the time this chemical action is going on, the copper sulphate solution in the outer cell is being constantly weakened.

In the first place, the hydrogen at the porous cell robs it of its SO_4, and in addition to this, its other constituent, copper, is being deposited on the wall of the copper pot.

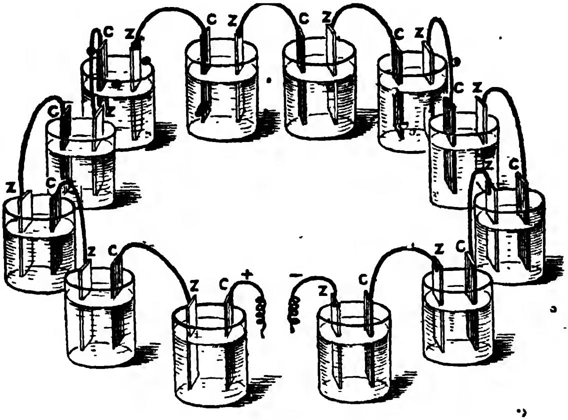


You remember, of course, that the solution itself and the crystals on the shelf are in contact, and the result is that the liquid is constantly dissolving the crystals, so that the two-fold loss is being constantly made good, and the solution is kept at the proper strength.

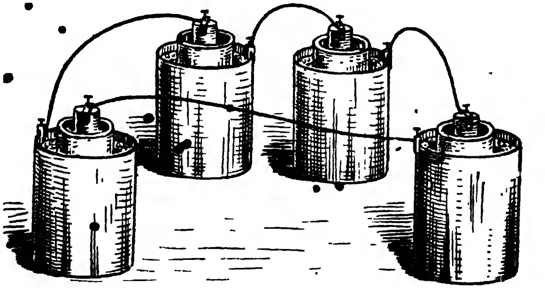
I might point out in passing that this is only one form of a two-fluid voltaic cell. There are others; but the object in all of them is to get rid of the hydrogen as quickly as it is formed.

It is usual, in order to increase the strength of the current, to group two or more cells together by means of conducting wires, and such an arrangement is known as a voltaic battery.

The earliest form of battery was devised by Volta himself, and he named it his Crown of Cups. It con-



sisted of a number of glass vessels arranged in a circle, with a zinc and a copper plate in each, the copper of the first connected by wire with the zinc of the second, and so on round the circle.



The series of simple cells thus connected produced a strong current for a time, but as the hydrogen accumulated the current gradually weakened.

Three or four Daniell cells, similar to the one we have been dealing with, make a very useful battery; but the cells are connected in two different ways.

In the compound circuit, the rim of the copper pot (the positive pole) of the first is connected with the top of the zinc rod (the negative pole) of the second, the copper of the second to the zinc of the third, and so on.

In the simple circuit, the battery is fitted up by connecting all the zincs together and all the coppers together.

Summary of the Lesson

1. The object of the two-fluid cell is to get rid of the hydrogen before it has time to reach the negative plate.

2. In the Daniell cell this is accomplished by the copper-sulphate solution in the outer cell.

3. The liberated hydrogen breaks up the copper sulphate ($CuSO_4$) into Cu and SO_4, uniting with the SO_4 to form H_2SO_4 and setting the copper free.

4. This constant weakening of the solution is constantly made good by the dissolving crystals on the shelf.

5. In all two-fluid cells the one object is to get rid of the hydrogen.

6. Two or more cells grouped together by conducting wires form a Voltaic Battery.

7. The earliest form of battery was devised by Volta, and was called a crown of cups.

8. The cells of a battery may be connected in a simple or compound circuit.

Lesson LXIII

The Battery at Work

Now that we know the nature of our voltaic battery, it will be well to set it to work, and find out what it is capable of doing.

For our first experiment we shall require a battery of two Daniell cells, fitted up and connected in the usual way.

Then, in addition to the battery, I have here in the retort stand a kind of vessel made for the purpose out of an ordinary glass funnel. Part of the stem of the funnel has been sawn off, and the rest has been filled up with plaster of Paris, so as to convert the funnel itself into a sort of bowl.

Through the plaster of Paris two copper wires pass, and these wires thus embedded are insulated, because plaster of Paris is a non-conductor.

The lower ends of the wires are left free, to be connected with the poles of the battery, but to the upper end of each a small strip of platinum foil has been soldered, and the two platinums are so arranged that they stand parallel to each other in the centre of the bowl, but without touching.

Then lastly I may point out that, as the vessel is intended to hold water, the plaster has been coated with a layer of melted paraffin wax, to make it water-tight.

The contrivance so arranged is called a voltameter: let us see how it is used.

We fill the bowl itself about three parts full of water, which has been slightly acidulated by the addition of two or three drops of sulphuric acid, to make it a better conductor.

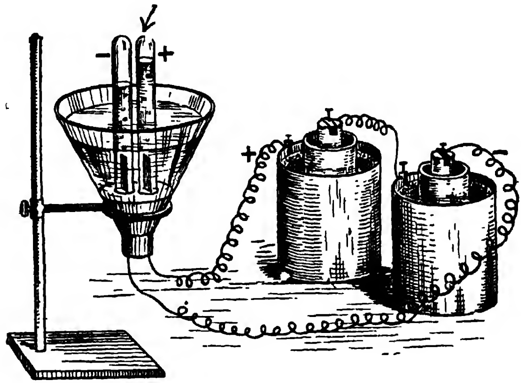
The next step is to fill two small test-tubes of equal size with the same acidulated water, and invert them below the surface, one over each platinum.

Nothing then remains but to connect up the ends of the wires with the two poles of the battery, so that

one platinum is in connection with the positive, the other with the negative pole.

Immediately that is done the current starts, and we see bubbles rising up each tube, and displacing some of the water at the top.

While this is going on let me explain that the platinum plates are called electrodes, from a word which means a path or a way. They are attached



to the wires to form broader paths for the electric current to enter the liquid.

One, as you observe, is connected with the positive pole of the battery, and that is called the positive electrode. The other, which is in similar connection with the negative pole, is the negative electrode.

I need scarcely point out that the bubbles, which are rising up each tube from the platinum electrode below, are bubbles of gas.

You can see for yourselves, too, that as the gas rises the water sinks in both tubes; but you also

observe that the volume of gas in the tube over the negative electrode is double that in the other tube.

When you are tired of watching these bubbles, we will endeavour to learn something about the gas in each tube.

Let us begin by removing the tube from the negative electrode. As I do so the water runs out of the tube, and when I thrust this lighted splinter of wood into it, the gas itself takes fire, and burns with a pale blue flame, while the flame of the splinter itself is extinguished.

Yes, I see you are eager to tell me all about it. The gas which collected in this tube was hydrogen, for no other gas takes fire, and burns with a blue flame, as that does.

We will now remove the other tube in the same way, and as the water runs out, I will plunge into it a red-hot splinter of wood. In this case, you see, the red-hot spark bursts into a brilliant glow, but the gas itself does not take fire; and you at once know that this must be oxygen, for no other gas acts in that way.

Hence it is clear that hydrogen has been collected at one electrode and oxygen at the other.

The electric current has been busy breaking up the water into its constituent gases, attracting hydrogen to the negative, and oxygen to the positive electrode.

Water, you know, consists of two parts hydrogen and one part oxygen, and you saw for yourselves that the volume of gas collected over the negative electrode was actually double that collected over the positive electrode.

This method of decomposing water into its two constituent gases by means of an electric current is

known as electrolysis, and the vessel in which it takes place is called an electrolytic cell.

The latter part of the name comes from the word *lysis*, which means a loosening or separating, and as this separating is effected by an electric current the process is known as electrolysis.

But the electric current is able to decompose other things besides water. Indeed, I will at once proceed to give you a brief description of two very important processes which are carried on by electrolysis.

No doubt you have all seen printers' type, and you know how the printer sets up the letters, side by side, and line upon line, to form a great sheet of printed matter.

Printing is rarely done from the type itself, however, because the type-letters are wanted for further use, and in order to release them a metal copy is made of the whole sheet, or block, after it has been set up. The metal copy is used for printing purposes, and the individual type-letters are thus set free.

Let me explain how this metal copy is made.

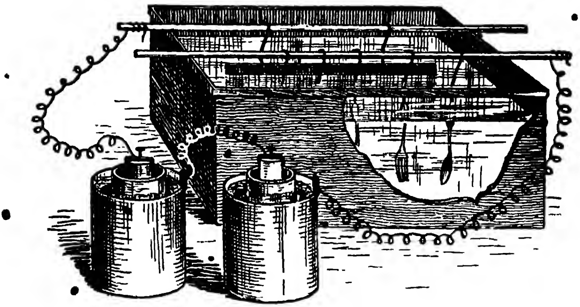
The first step is to get a gutta-percha mould of the block, by pressure. Then this mould is hung in a vessel containing copper sulphate, and a plate of copper is also suspended in the same liquid. The two are then connected with the wires of a battery, the copper plate thus becoming the positive electrode, the mould itself the negative electrode.

The rest is easy. The current from the battery decomposes the copper sulphate, and deposits its copper on the negative electrode, that is, on the surface of the mould. Then, too, as the solution is weakened by the removal of this copper, the liberated SO_4 group is

attracted to the copper plate, which is the positive electrode, and robs that plate of some of its copper to make fresh copper sulphate, because it cannot exist alone.

In this way the strength of the copper sulphate solution is kept up, although the current is constantly robbing it of copper, which it deposits on the mould, where it forms an exact copy of the original type.

Electroplating, another very useful art, is simply the result of electrolysis. By this process copper and



other common metals can be coated with gold or silver, and they are then said to be plated.

The process is similar to that of electrotyping. Let us suppose that some article is to be plated with silver. In that case a vessel, commonly called the electric bath, is filled with a liquid which contains silver in solution.

The article to be plated is hung in this electric bath, and becomes the negative electrode, while a plate of silver is also hung in the same liquid, and forms the positive electrode.

The current from the battery, as before, decomposes

the liquid, and deposits the silver from it on the surface of the metal article. While that is going on, the constant weakening of the solution by the removal of this silver is being constantly made up by an equal amount of silver, dissolved from the plate which forms the positive electrode.

Summary of the Lesson

1. The decomposition of water by means of an electric current is called electrolysis.

2. The vessel in which it goes on is called the electrolytic cell.

3. The two platinum plates are called electrodes, because they form broader paths for the electric current to enter the liquid.

4. One electrode is connected with the positive pole of the battery, the other with the negative pole.

5. Hydrogen collects at the negative electrode; oxygen at the positive electrode.

6. Electrotyping and electroplating are both accomplished by electrolysis.

Lesson LXIV

More Work with the Battery

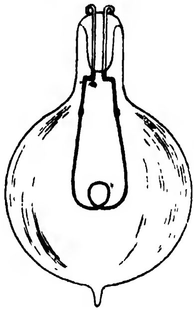
I need not remind you of the use which is made of electricity for lighting purposes, for every one is familiar nowadays with electric light. It is no part of our business here to inquire into the various forms of electric light. We will therefore content ourselves with a few words about the construction and working of the ordinary incandescent lamps, which are now so common everywhere.

If the ends of the copper wires from the two poles

of a battery are connected with an inch or so of very fine platinum wire, the current immediately begins to flow, and the platinum gets very hot. Indeed, if a sufficiently strong current is produced, the platinum becomes first red-hot and then white-hot, and in the latter state it gives out a white light of dazzling brightness.

The knowledge of this fact led to the construction of those incandescent lamps, although carbon is now used in preference to platinum, because platinum wire is liable to fuse with a very strong current.

The lamp itself is a closely-sealed glass bulb, from which the air has been exhausted, and it contains a loop of carbon, which is connected with the wires of a battery.



The current passing along the wires makes the carbon loop intensely hot, and in that state it sends out a brilliant white light, but it cannot burn away, because there is no air, and of course no oxygen, in the bulb.

We will now finish up with an experiment, which I think will be a great surprise to you.

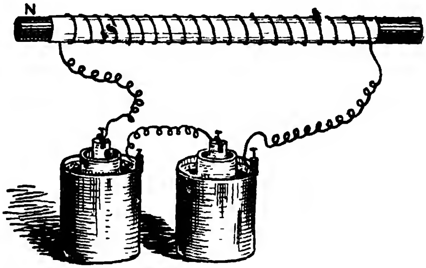
I have here a bar of ordinary iron which I will roll up in a sheet of paper. That done, I will wind a coil of insulated copper wire round it in the form of a spiral from one end to the other, and then connect the two free ends of the wire with the two poles of the battery.

As soon as the connection is made, the current of course starts.

Now observe what happens when I dip either end

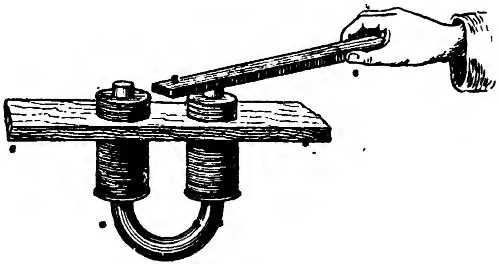
of the bar into this heap of iron filings. The filings cling in a cluster at each end.

You observe too that, if I present this end of the bar to each pole of the magnetic needle in succession,



it attracts one and repels the other; and if I repeat the test with the opposite end the result is the same—it attracts one pole and repels the other.

The bar, you see, is now a magnet; it has been



made a magnet by the electric current, and we therefore call it an electro-magnet.

But I will remove it from the wire coil now, and test it again in the same way, and you observe that all trace of its magnetic force is gone.

It is no longer a magnet: it was a temporary magnet only while under the inducing influence of the electric current.

In our lessons on magnetism we noticed some of the ways in which magnets are made; but electro-magnets are always employed for making large permanent magnets.

Bars of steel, not soft iron, however, are used for this purpose, and they are drawn across the pole of a powerful electro-magnet.

Electro-magnets are of immense importance in the arts, for the electric bell, the electric telegraph, and the telephone are all worked through their agency.

Summary of the Lesson

1. A very strong electric current raises carbon or fine platinum wire to a white heat.

2. If the carbon or platinum wire is placed in a vacuum it gives out an intensely bright light, but cannot burn away because of the absence of oxygen.

3. A bar of iron under the inducing influence of an electric current becomes a temporary magnet.

4. We call it an electro-magnet.

THE END

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